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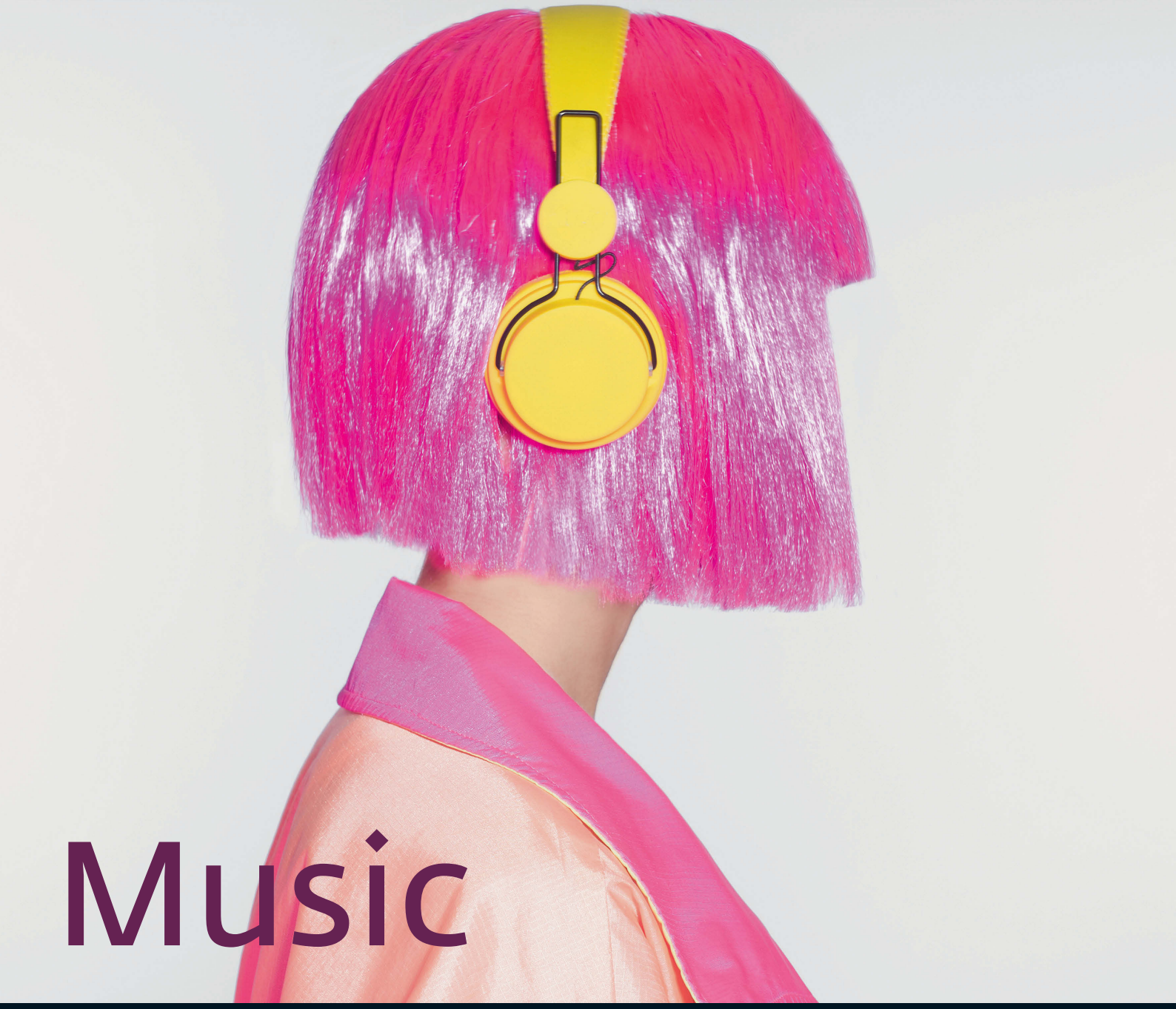
Max Planck RESEARCH

The Science Magazine of the Max Planck Society 4.2015



Music

REFUGEE CRISIS
Germany's Second Turning Point?

CELL BIOLOGY
Nano-Sized Lethal Injection

ASTRONOMY
Archaeology of the Milky Way

BIOGEOCHEMISTRY
Drilling Deep into Earth's History

SIEMENS

Pictures of the Future

The Magazine for Research and Innovation

Dossier – IT Security

Digital systems have become indispensable for many sectors of the economy. However, when large amounts of information are stored anywhere, criminals are never far away. The order of the day is therefore to find effective solutions that offer the maximum possible protection against intruders from the Web.

Photo: Andrew Crozier/MPI for Chemistry

High-Tech in Vast Expanses

Its tip appears to reach all the way up to the stars. It may not be quite that tall, but the Amazonian Tall Tower Observatory, known as ATTO, is nonetheless a project of superlatives: 15,000 individual components, 24,000 screws and bolts, a total weight of 142 tons on a ground area of a mere 3 by 3 meters, all pretensioned using a total of 26 kilometers of steel cable. And at 323 meters, ATTO is taller than the Eiffel Tower. The structure, located 150 kilometers northeast of Manau in the middle of virtually impenetrable Amazonian rainforest, was erected in just one year.

However, it's not only its height that makes ATTO so special; a crucial factor is the ecosystem that surrounds the tower: Like its counterpart, ZOTTO, the 304-meter-tall measurement tower in the Siberian taiga, ATTO is far removed from the influence of civilization. Scientists can therefore expect it to be provided with largely unadulterated data on climate events in the atmosphere above the Earth's largest uninterrupted expanse of forest.

Although all of the measurement equipment has not yet been installed in the tower, it will soon provide a constant stream of data about greenhouse gases, aerosol particles, cloud properties, boundary-layer processes and the transport of air masses. The researchers are particularly interested in the interaction between the rainforest and the masses of air streaming above it. After all, the Amazon region is of global importance for the climate, and too little is currently known about the role the rainforest plays in the formation of aerosol particles and thus cloud formation.

The Max Planck Institute for Chemistry in Mainz and the Max Planck Institute for Biogeochemistry in Jena are partners in the joint German-Brazilian ATTO project. The measurement data recorded by ATTO flows into current models for forecasting climate development and will also soon help politicians develop environmental policy regulations and global climate goals.

https://www.youtube.com/watch?t=5&v=e--sa5uFGBo

18 MUSIC

ON THE COVER If the surveys can be believed, about a quarter of all Germans listen to music for one hour every day. Young people, in particular, do so in public – teens with more or less conspicuous headphones are an everyday sight in subways and on the streets. This is reason enough for our magazine to dive deeper into the subject of music. In this issue we look at listening habits, emotions and moods. The researchers turned up some surprising information.

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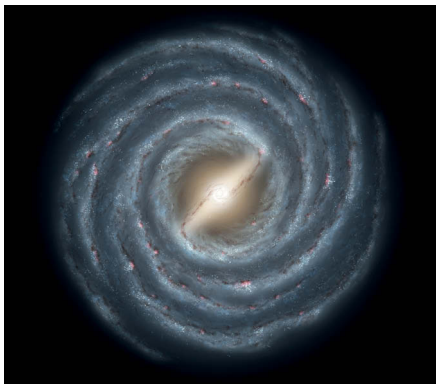
Cover: shutterstock; photos this page: Fotolia (large image), Frank Vinken



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Photos: Robert Hurt/SSC/Caltech/JPL/NASA Robert Hurt, David Ausserhofer, Tom Pingel (from left to right)

SPECTRUM

BIOLOGY & MEDICINE

PHYSICS & ASTRONOMY

MATERIAL & TECHNOLOGY

ENVIRONMENT & CLIMATE

REGULAR FEATURES

Cooperation under the Banner of Innovation

Ten years of collaboration between the Max Planck Society and the Fraunhofer-Gesellschaft

The cooperation program is aimed at creating knowledge for application and putting new solutions into practice. The two partners each specifically support projects that bring the core competencies of their respective organizations to bear: for the Max Planck Society, that is discovery-driven basic research, and for the Fraunhofer-Gesellschaft, it is industry-centric technology development. The research organizations make up to four million euros available for the undertaking each year.

"This is an important contribution we are making to Germany as a location for innovation," says Max Planck President Martin Stratmann. He explained that the program is based "not on a sequential concept of collaboration, but on an integrative understanding of it." Consequently, it isn't as if the Max Planck scientists hand over the findings of their basic research to their Fraunhofer colleagues: "What we actually do is have all parties work together from the start with the focus firmly on discovery and solutions." The spectrum of topics covered ranges from new types of high-capacity magnets to early testing for dyslexia to improved investigation and restoration methods for the ancient site of Pompeii.

Vividly illustrated: Fraunhofer President Reimund Neugebauer (left) and Max Planck President Martin Stratmann presented their joint projects in Berlin.

Thought Leaders in Religion and Modernity

Alexander von Humboldt Foundation and Max Planck Society honor Bryan S. Turner and Hans Joas

What is the significance of religion in our day? What is it that ensures cohesion in multicultural societies? It is on questions like these that social philosopher Hans Joas and religion sociologist Bryan S. Turner have produced groundbreaking efforts toward explanations and solutions. The two scholars firmly believe that the widely claimed secularization of modern societies is merely a highly simplified view of the matter. According to Joas, even non-religious people have something akin to religious experiences, such as through striving to find the meaning of life, pursuing a higher goal, or in the relationship with a loved one.

Turner, on the other hand, focuses on matters pertaining to law. In light of social, cultural and religious pluralization, the law serves as an anchor of social cohesion. The Max Planck Research Award is funded by the German Federal Ministry of Education and Research and is endowed with 750,000 euros for each recipient. The award ceremony took place in Berlin on December 8.

Reflective: Bryan S. Turner (left) and Hans Joas focus on secularization and religious plurality.

Photos: Amac Garbe (top), University of Potsdam, K. Fritze/Britt Schilling

Ironic Prize for a "Huh?"

Max Planck linguists win the Ig Nobel Prize for Literature

The Ig Nobel Prize is bestowed every year to "honor achievements that make people laugh and then think." And that is just what some of the findings emerging from the Max Planck Institute for Psycholinguistics in Nijmegen do: Mark Dingemanse, Francisco Torreira and Nick Enfield discovered that little words like "huh?" are the cement that holds interpersonal communication together. People around the world use them to signal that they haven't understood what someone was saying to them. The Ig Nobel Prize enjoys cult status in English-speaking countries, where self-deprecation is part and parcel of polite conversation. Indeed, many young award winners have gone on to enjoy a career in science. The most prominent among them is Andre Geim, who won the Ig Nobel Prize in 2000, followed by the Nobel Prize in Physics a decade later.

These findings from Nijmegen were actually only a by-product of a larger research project on how people worldwide "repair" misunderstandings in communication. In parallel with receiving the Ig Nobel Prize, the team was able to publish new and insightful findings: Besides the "huh?" interrogative, they discovered in different languages two other universal strategies whereby listeners interrupt the conversation and pose a question to clarify what has just been said.

Universal: German speakers say "häh?", English speakers "huh?" and Icelandic speakers "ha?" when they haven't understood something. Max Planck researchers discovered similar interrogatives in 31 languages.

Illustration: MPG, based on original material from shutterstock

Novel Imaging System for Cell Analysis

Start-up raises a million for innovative application

The Stuttgart-based company Venneos GmbH is working on a new type of imaging system for analyzing biological cells. A consortium comprising Business Angels and Family Offices, the High-Tech Gründerfonds and the Max Planck Society is investing in the company to develop the product to market readiness and prepare the first generation for market launch. Venneos, a spinoff of the Max Planck Society, is working on a silicon-chip-based imaging system for analyzing biological cells. The system is based on an innovative measurement method that allows customers to recognize cellular changes that other technologies can't detect.

The company is currently refining the prototype in conjunction with pilot customers. "The cooperation with customers demonstrates that there is a need for Venneos' new systems both in academic research and in drug development," explains Jonas Lehmann, one of the founders.

"Complicated rules that very few are happy with"

Interview with Jens Beckert from the Max Planck Institute for the Study of Societies on the inheritance tax reform

In 2014, the German Federal Constitutional Court declared the law on inheritance tax and capital transfer tax unconstitutional because it doesn't tax business assets to the same degree as other types of assets. The exemption rules in place for companies gave them an unfair advantage. The reform has been initiated, and a draft law is currently facing opposition, predominantly from the business sector. This isn't a new topic for Jens Beckert. The Director at the Max Planck Institute for the Study of Societies already presented a sociology of inheritance law in 2004, and published a book on inheritance in an achievement-oriented society in 2013.

Last year, the state received around 5.5 billion euros in inheritance tax from estates worth an estimated 250 billion euros. Why is that so little?

Jens Beckert: Although tax rates are up to 30 percent for close relatives and even as high as 50 percent for non-related heirs, the figures show that estates are taxed at just slightly more than 2 percent on average. There are various reasons for this. First, the tax-free thresholds are high. In a family situation with an inheriting spouse and two children and a family home involved, it is ultimately possible to bequeath assets worth almost two million euros tax free. But few estates are that large. Second, business assets are almost completely untaxed. And then there are tax loopholes that can be taken advantage of.

Low-income earners inherit less, and less often. If that is so, why is inheritance tax still frequently perceived as unjust?

Because the tax exemptions are so high, very few heirs will ever have to pay inheritance tax. And half of the population doesn't inherit anyway. Nevertheless, opinion polls regularly show how strongly people dislike the tax. This isn't something we fully understand. Many people simply don't know that, where close relatives are concerned, inheritance tax affects only very large estates. And many people see inheritances as a purely family affair, and think that the state should keep its nose out. Another explanation is that – just like playing the Lotto – people hope they'll one day receive a surprise inheritance, and then they won't want to share it with the government.

Why does Germany need an inheritance tax when numerous European countries don't have one?

The trend in the distribution of wealth in past decades indicates an increase in social inequality. This can eventually prove detrimental to economic development and democracy. Inheritance tax can serve as a corrective element by reducing the value of large estates when passing them on to the next generation, and thus create more equality of opportunity.

What would you say to people who insist that inheritance tax is taxing income twice?

I consider this argument to be wrong. Inheritance tax is collected from the heir to the estate. The heir hasn't paid tax on this income before. When you buy a loaf of bread from the bakery, the baker has to pay tax on the money you hand over even though you've already paid tax on it yourself.

What do you think of the reform as it concerns business assets?

The proposed reform that's been before the cabinet since the summer is going to create complicated and ambiguous rules that very few are happy with. The underlying problem of business assets being virtually untaxed remains unresolved, in my view. But as for how we can tax companies in the event of succession without hampering their competitiveness – I think it's impossible. What was particularly interesting about the judgement of the German Federal Constitutional Court was the minority vote of three judges who declared that inheritance tax serves not only as a means of bringing in tax revenues, but also as an instrument of the welfare state. They said that wealth shouldn't be able to accumulate in the hands of the few over many generations on the grounds of birth alone. This is a new notion, at least in the recent case law emerging from the Court.

Jens Beckert

What would be your personal ideas on how inheritance tax should be structured?

I would argue for higher inheritance tax. Estates passed down should be taxed – after the deduction of tax-free limits – at the same rate as income. This would fit much better into our self-understanding as an achievement-oriented society. Why do we tax the work we do at up to 45 percent, but tax inheritances passed down to close relatives – where most estates do go – at no more than 30 percent? And that's only for estates worth 26 million euros or more! The additional tax revenues could be used to reduce income tax, which would create additional economic incentives.

What do you think of the proposal to have a single low tax rate?

The appeal of a single low tax rate of the kind the German Finance Ministry's scientific advisory board has proposed lies in the fact that it could drastically reduce the number of complex valuation rules and exceptions inherent in inheritance tax law. From the perspective of tax practice, this is an understandable objective. But it would mean giving up the goal of using inheritance tax as an instrument for correcting unequal opportunities in our society.

Interview: Susanne Beer

Photo: Matthias Jung/MPI for the Study of Societies

Liftoff for LISA Pathfinder

Satellite on its test mission in space

LISA Pathfinder is the test mission for the planned *eLISA* gravitational wave observatory. "The satellite contains brand new technologies with which we aim to later capture the sound of the universe," says Karsten Danzmann, Director at the Max Planck Institute for Gravitational Physics in Hanover. *LISA Pathfinder* will test the technologies in outer space. A crucial element, the optical precision measurement system, was developed and built under the supervision and with substantial involvement of the institute.

In recent weeks, the highly sensitive payload was installed in the satellite and the complete vehicle tested. *LISA Pathfinder* was launched into space from the spaceport in Kourou (French Guiana) on December 3. Meanwhile, the scientists are busy preparing for mission operations. As soon as *LISA Pathfinder* has reached its destination, they will test the technologies intensively, remaining in constant dialog with the satellite.

Tough test: The *LISA Pathfinder* scientific module and the drive module with thermal insulation before acoustic testing at IABG in Ottobrunn. Tests have ensured that the probe can withstand undamaged the enormous acoustic vibrations to which it will be exposed when starting its journey into space.

Photo: ESA-P. Sebriot, 2015

On the Net

The Max Planck Society in 75 Seconds
Knowledge is everything. And basic research helps us understand our world better and expand our horizons. The Max Planck Society has long been a special place for elite scientists engaged in basic research. What is it that sets us apart? A new video clip explains this with the help of sketchboard animations that accompany the narrative, illustrating the action in pictures – easy to understand and presented in just 75 seconds.
https://www.youtube.com/user/MaxPlanckSociety

Post from …
Max Planck scientists cooperate with partners in some 120 countries around the world. In the course of their work, they also learn about everyday life in different cultures. Take quantum physicist Nora Kling, for example, who discovered a new and fascinating world on a visit to a laser lab in Riyadh, or Adrin Jalali, an Iranian doing his doctorate at the Max Planck Institute for Informatics in Saarbrücken: he talks about his experiences in a small German town and why he never wants to return to Tehran. The popular series from MaxPlanckResearch is now also available online at:
www.mpg.de/9359216/internationality

Painting with Light
Within the framework of the International Year of Light 2015, the Max Planck Society held a light painting contest that attracted numerous entries. Light painting is a photographic technique in which exposures are made by moving a hand-held light source while taking a long exposure image. The top prize was participation in a light painting workshop with the *Lichtfaktor* artist collective. The winners were recently selected and you can see the prize-winning pictures at:
www.deutschland-geht-ein-licht-auf.de/einreichwettbewerb

Germany's Second **Turning Point?**

For weeks the influx of refugees has continued to surge. Via what has become known as the Western Balkans route, thousands of people from different regions, including the war zones in the Middle East, have set out on foot in hopes of reaching Europe. The mass immigration of refugees will fundamentally change Germany. But the question is: how?

TEXT **STEVEN VERTOVEC**

Current estimates suggest that Germany might expect about one million refugees this year. Chancellor Angela Merkel has clearly recognized that such an unprecedented influx will fundamentally change Germany. The Vice Chancellor, Sigmar Gabriel, has further surmised that Germany may well receive over 500,000 people per year in the near future. While he is confident that Germany will be able to successfully handle such a large-scale influx of migrants, he admits it will be the country's biggest challenge since *die Wende* (the most common term for the "change" or "turning point" in German society following the fall of the Berlin Wall and German reunification).

> Germany is experiencing a huge wave of immigration that will fundamentally change the country

Is the societal change that Germany now faces tantamount to *die zweite Wende*, or "second turning point?" A recent New York Times cartoon suggests as much, depicting "the fall of the wall all over again" with Angela Merkel and jubilant Germans welcoming refugees through a demolished wall between the global North and South. If the current inflow of people represents a social transformation of proportions similar to that of the German reunification, what might such change entail?

One should be cautious not to overstretch the comparison between what is being called the current refugee crisis and the *Wende*, because – just like the political cartoon – it is meant in a metaphorical sense. Suffice it to say that any profound event of this nature necessarily results in or will result in far-reaching political, economic and social restructuring. Twenty-five years after German reunification, the process is still not complete. >

Illustration: Chappatte in The International New York Times, Sep 09, 2015


THE FALL OF THE WALL, ALL OVER AGAIN!
Welcome to Germany
NORTH
SOUTH
EU
CHAPPATTE
International New York Times

The former East and West regions of Germany still significantly diverge, both socio-economically and in terms of public attitudes. Transformations following the current, large-scale wave of immigration will also be far-reaching and will take decades to fully unfold. They will also likely have highly divergent outcomes across German society.

Gabriel's conjecture that 500,000 or more new arrivals might reach Germany each year in the foreseeable future is likely correct. It is, in fact, right to assume that a growing number of people will immigrate into the country. After all, one thing we know from migration theory is that new migration leads to more migration. As people move across borders, the expansion of transnational social networks – now augmented by smartphone technology – facilitates information-sharing to family members and friends who stayed behind about modes and routes of travel, job-seeking, acquisition of housing and more.

New migration leads to more migration

Furthermore, the causes of present-day migration aren't going away. Migration rarely has just one single trigger, and hardly ever is it either only forced or only voluntary. Migration has multiple roots. Most of the time, several factors compound or reinforce each other.

The reasons that drive people to migrate are manifold. They can be political (civil war, terrorism, political oppression or persecution), social (family strategies to improve living conditions), economic (chances of securing sustainable wages and access to goods and services), demographic (population size or density, especially with regard to the local labor market) or environmental (different types of soil degradation and consequences of climate change that endanger lives and livelihoods).

This interaction of multiple causes makes it increasingly difficult to find solutions to the migration problem – and that currently applies to almost every country from which new arrivals are coming to Germany in this refugee crisis. The constellation of compound migration causes is wholly different in each country, and none of these causes can be ameliorated in the near future. In fact, it is highly likely that particularly the driving forces related to environmental deterioration will continue to increase and will significantly influence all other causes.

It must be said that the influx of migrants from abroad is certainly not a new phenomenon in Germany. Over the past fifty years there have been successive waves of new migration. From the 1950s to the early 1970s, newcomers were comprised largely of Italians, Yugoslavs and Turks who shared a status of "guest workers" (*Gastarbeiter*). Family reunification during the 1980s and 1990s saw a further expansion of these national groups. Since the 1990s – when there was also a massive inflow of refugees from war-torn Yugoslavia – Germany has been witness to changing inflows from countries across the globe. This has amounted to a considerable diversification of the immigrant population.

The number of countries of origin from which migrants came to Germany kept rising. Today, people from more than 200 different nations live in Germany. Over the past twenty years, in Germany (as elsewhere around the world), a new migrant diversity has been layered on top of an earlier one.

These waves of immigration and diversification have been, on the whole, experienced favorably in Germany across all social backgrounds. This is shown in the annual "Integration Barometer" compiled by the Expert Council of German Foundations

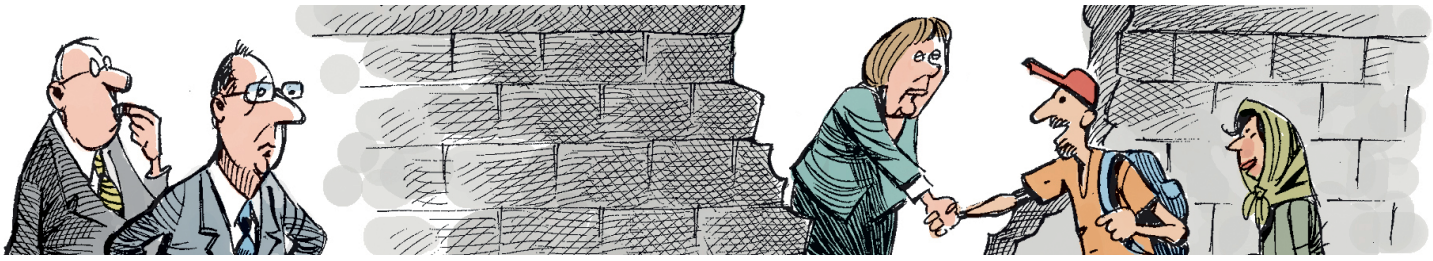


Illustration: Chappatte in The International New York Times, Sep 09, 2015

on Migration and Integration, which depicts a generally pragmatic and positive attitude toward issues of migration and integration among Germans and migrants alike. At the Max Planck Institute for the Study of Religious and Ethnic Diversity, a multi-disciplinary research project carried out in 16 German cities also demonstrates surprisingly high levels of contact between Germans and people with migration backgrounds.

Only 16 percent of Germans interviewed as part of the "Diversity and Contact" (DivCon) research project said they "never" had a conversation with people with migration backgrounds; about half said they have such contact "daily" or "weekly". This shows that, for many people – especially in cities in western Germany – interaction between Germans and immigrants is a normal part of daily life. Moreover, such contact notably tends to be valued positively by all with or without a migration background.

Now, with the current inflows of migrants, an even newer diversity is being layered upon an already diversified population in Germany. Syrians, Afghans, Pakistanis, Eritreans, Somalis, Nigerians and Iraqis make up a large proportion of today's new arrivals, along with continued high numbers of people from Serbia, Kosovo and Albania.

They are coming to Germany at the same time as the continued immigration of people from other countries, especially from Spain, Portugal, Italy, Greece, Poland and Bulgaria. Yet it is not increasing ethnic or national diversity that will pose the greatest challenges for German society. Rather, it is much more likely that the biggest challenges will surround the differing legal statuses of newcomers.

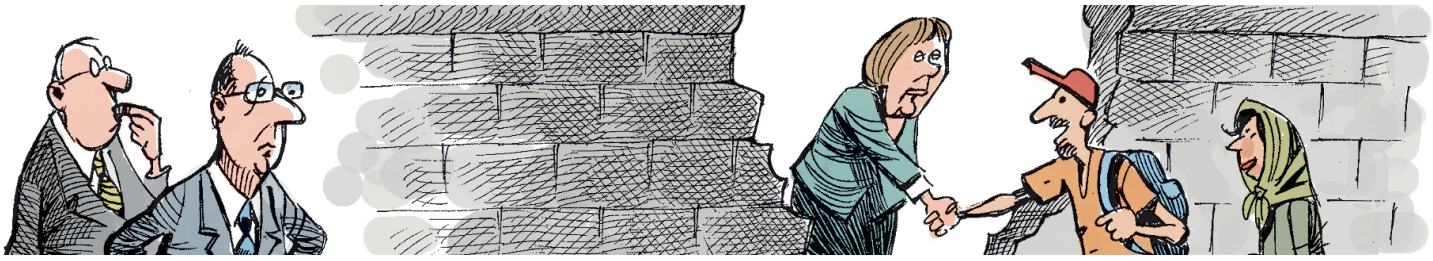
Like most Western democracies, Germany sorts and deals with newcomers by way of differential migration channels, tracts and legal statuses. For example, there are: EU migrants, temporary or seasonal workers, highly skilled and corporate migrants, asylum seekers, officially recognized refugees, people with temporary residence permits or temporary suspension of deportation (*Duldung*), arrivals through family reunification, students, failed asylum seekers, people with lapsed visas and undocumented migrants.

Each status entails different opportunities and restrictions in many areas. These include issues concerning: permission to work, type, orientation and processes of integration into the labor market, type of employment contract, employment conditions and wages; length and nature of residence, prospects of family reunification, entitlement to welfare and healthcare services, access to education and public services, legal and political representation, chances for permanent settlement, and the possibility of gaining citizenship.

The biggest challenges will surround the differing legal statuses of the newcomers

Migration statuses have implications for individuals' earnings, health outcomes, housing, social network formation, integration into neighborhood life, and family dynamics. Legal status outcomes are therefore often intrinsically related to creating or perpetuating modes of social inequality, and assign people to situations and circumstances from which they often find it hard to escape.

So what might happen in the near future, when people keep migrating to Germany and the euphoric "Refugees welcome!" attitude has waned? According to available social-scientific analyses, the following developments are plausible: As with the previous waves of immigration, cordial if not positive



encounters are likely to be commonplace. There will be frustration, but also eventual accommodation.

Language will almost certainly be a key frustration point. Yet more and more Germans will learn to find communicative middle ground with those who have less than fully competent German language skills. In turn, the newcomers will learn the ordinary, small and habituated proprieties, phrases, gestures, acknowledgements, and do's and don'ts that Germans have internalized. Just like before the current wave of immigration, practices of uneventful, everyday living together across the country will go largely unnoticed.

Even though the generally positive atmosphere could very well last, there will doubtless be problems aplenty. Occasionally, social tensions will flare. Ugly incidents involving racist reactions will occur intermittently, but in isolation. Movements of the far right will probably not expand much beyond their current size (which is not very extensive at the moment). A lot will depend on whether and how migrants gain access to the labor market. (Previous experience has shown that this does not have a considerable impact on the unemployment rate. In fact, migrant integration into the labor market often creates some new jobs, while wages at the lower end of the scale potentially feel the pressure. However, there are few comparable cases of simultaneous immigration of such magnitude.) Municipal resources will be burdened, and institutions such as schools, healthcare and social facilities, as well as the housing market, will face significant challenges.

This will influence the political debate at all levels. And while some politicians will highlight successful examples of integration, others will leap at any negative instance to bark "I told you so." This type of political discussion is sure to worsen should Germany experience an economic slump (for example if Chinese growth continues to slow down). Fingers will be pointed at migrants and the blame game will be played, exacerbated and exploited at every opportunity.

As far as positive or negative images, relationships and debates are concerned, there will be noticeable discrepancies not just between the traditionally open-minded larger cities, on the one hand, and the smaller towns and villages on the other, but especially between East and West. Before the refugee crisis, between 18 and 27.5 percent of the population in Germany's western states came from a migration background, while only 3.4 to 4.6 percent of people in the eastern states were migrants. There is a common tendency to view immigration more negatively in places with fewer migrants.

> Stereotyping creates an image of the "good" and the "bad" immigrant

Everywhere, however, public attitudes and representations will likely transform, or crystallize around, ethnicized images of "good" and "bad" immigrants. Through processes of stereotyping, in many people's eyes, certain national groups will be positively valued while others are stigmatized. However, many actual problems, stigmas and forms of social stratification that arise around new migration will have far less to do with ethnicity, nationality and the presumably associated cultures than with migrants' respective legal statuses, which have such a decisive impact on where and how people live. The crucial role of the media will be to ensure that their news coverage focuses less on ethnicizing problems and more on identifying the underlying structural causes.

Illustration: Chappatte in The International New York Times, Sep 09, 2015

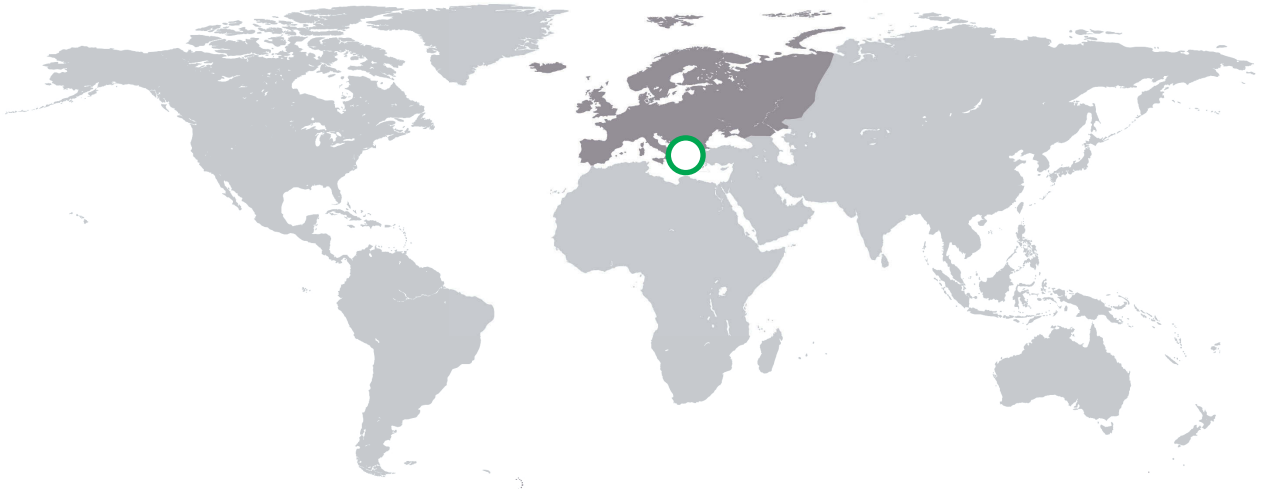
The overall future picture is of a very uneven social landscape, with inequalities and discrepancies distributed unequally across the country. There will be more and less successful examples of "integration" (a word asked to do far too much work, since it can mean very different things when used in relation to education, the labor market, social relations, cultural values and language acquisition). The ongoing task for politicians, the media and academics will therefore be to define, identify and understand – in different places around Germany – the complex set of factors, processes, practices, institutions and resources that contribute to what counts as more or less success.

Today, it is conventional in Germany to use the phrase "since the turning point" ("*seit der Wende*") to refer to any substantial post-reunification development. And while speaking of a "second turning point" might be a bit overstated, the social transformations facing Germany will be of such an order that, in the future, "since the refugee crisis" ("*seit der Flüchtlingskrise*") might be as familiar a phrase. ◀

THE AUTHOR

Steven Vertovec was born in Chicago, Illinois in 1957. He studied anthropology and religious studies at the University of Colorado and later received his master's degree from the University of California, Santa Barbara in 1982. He moved to the United Kingdom for his doctorate at the University of Oxford, where he subsequently became Professor of Transnational Anthropology and Director of the Centre on Migration, Policy and Society. In 2007, Steven Vertovec was appointed Scientific Member and Director at the newly founded Max Planck Institute for the Study of Religious and Ethnic Diversity, based in Göttingen. Vertovec has served as an expert and advisor on migration-related issues to British ministries, the World Bank, the European Commission, the G8 Forum and UNESCO. He consolidated his core theories on migration in the concept of superdiversity – a multi-dimensional understanding of increasing social complexity in many countries around the globe.

Photo: MPI for the Study of Religious and Ethnic Diversity



Hard-Earned Scientific Luxury

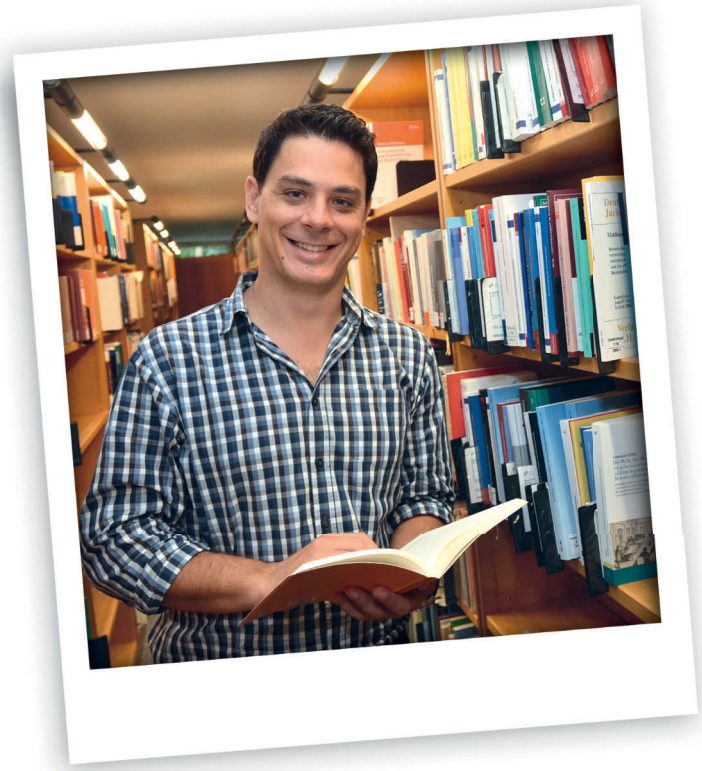
Scientists from 55 countries around the globe work at the Max Planck Institutes. Here they relate their personal experiences and impressions. Emmanouil Billis from Greece conducts his research at the Max Planck Institute for Foreign and International Criminal Law in Freiburg. It's not only the excellent working conditions there that have fired his enthusiasm: also the friendly environment makes Germany feel like a second home to the 31-year-old scientist.

For as long as I can remember, books have held a particular fascination for me. This gradually led to a growing interest in scientific research, especially where social and legal issues were concerned. Some years later, as a young law student, I was told that Germany had the best books in the world's best libraries. In fact, I recall these very words of one of my university professors: "If you wish to become a jurist and a legal scientist in Greece, you should definitely start in Germany."

"Well, maybe for a few years," I said, "and then I'll come back with all the academic skills I need to become a professor. I will then be able to use the knowledge I will have gained abroad where it is really needed." This is a typical career path for Greek researchers. After all, a lot of Greek scientists have earned their doctorates in Germany – primarily due to the deeply rooted humanistic and academic traditions that unite the two countries. This is particularly clear in my research field, which is criminal law. At the same time, however, I must point out that the Greek university system produces outstanding scientists and practitioners. There's a good reason why Greece has a very high proportion of researchers and academics working at the world's best universities.

After studying law and practicing it for a few years as an attorney, in 2009 I finally set off on my long-planned adventure abroad. First I headed to Bonn, where I intended to do my

Graphic: iStockphoto



Emmanouil Billis, 31, studied law from 2001 until 2008 in Thrace and Athens; he was admitted to the Athens Bar Association as a lawyer in August 2007. Between 2009 and 2010 he took part in the LL.M. program at the University of Bonn, where he defended his LL.M. thesis on procedural law and the European Convention on Human Rights before obtaining his doctorate at the Faculty of Law of the University of Freiburg within the framework of the International Max Planck Research School for Comparative Criminal Law. Since September 2010, Emmanouil Billis has been a member of academic staff at the Max Planck Institute for Foreign and International Criminal Law. His current tasks include preparing the country report for Greece as part of the "International Max Planck Information System for Comparative Criminal Law" project.

master's, just as the debt crisis in Greece hit the European headlines for the first time. It was in those days that I began to hear some odd comments from time to time, over a beer or when meeting strangers, when I told people where I came from. You know – the usual.

I come from a Greek middle class family, and it was this social class that was hit hardest by the tax increases – cutbacks and layoffs have been the general norm all this time. It was therefore a luxury for me, albeit a hard-earned one, to study at a German university. And you can't call me lazy, any more than you can call an entire generation of qualified graduates lazy who are unable to find a job in their home country because of the budget cuts.

But Bonn would be just the beginning for me in Germany – even then, my objective was to move to Freiburg and to the Max Planck Institute for Foreign and International Criminal Law, with its outstanding library and some of the finest legal scientists in the world. Besides the excellent working conditions, what I loved about the institute was that turned-up noses and ironic remarks had no place there; there were only well informed inquiries, concern and curiosity about how Greece can possibly overcome its problems, how my family was coping back home, and so on.

Of course, it's not easy to grasp the whole situation, as it isn't easy to establish a place for yourself anywhere in science. At home, though, this has become practically impossible. We want to do research, but we can't – at least not for the moment, and not for the next ten years, it seems. There are so many fundamental problems that need to be overcome before scientists who were trained abroad can come home again.

The traditionally outstanding education system that I benefited from in Greece is in urgent need of regeneration and financial support. And yet, despite the gloomy outlook, I know one thing: while the conditions abroad may be my best option for the moment, I will definitely go back in the next few years. My scientific future is in Greece. And coming back to the words of my professor: that's why I came to Germany in the first place.

Photo: Private collection

Changing Tastes in Music Styles

Rock or *Schlager*? Classical or country? Pop or techno? Musical taste reveals quite a lot about an individual's personality and status. However, listening habits are changing. Dyed-in-the-wool rock fans are dancing to German *Schlager* singer Dieter Thomas Kuhn, classical fans put Johnny Cash on while washing the dishes, and ravers listen to Chopin to chill. **Melanie Wald-Fuhrmann** and her team at the **Max Planck Institute for Empirical Aesthetics** in Frankfurt am Main are investigating the essence and roots of musical preferences and tracking shifts in musical taste.

Photo: Corbis

There may be no accounting for taste, but it can certainly be researched. Since ancient times, aesthetics has focused on the question of what people find beautiful and why.

TEXT **MECHTHILD ZIMMERMANN**

Who listens to particular styles of music and what is individual musical taste based on? For decades it was thought that a satisfactory general answer had been provided to this question: The elite attend classical concerts and play classical instruments, the middle class takes direction from the stratum above it by listening to light classical musical and other sophisticated easy listening, and the lower classes listen to pop and folk. This categorization derives mainly from the work of French sociologist Pierre Bourdieu. In *Distinction*, his influential work from 1979, he suggests that taste is not individual but is influenced by society, particularly through socialization in the family. Comprehensive studies carried out in the 1960s and 1970s formed the basis for this analysis.

Particular stereotypes are still associated with people's tastes in music today. Musicologist Melanie Wald-Fuhrmann makes use of this phenomenon when she lectures about her research to the public: "If I were to confess to you that my favorite music is that of *Schlager* singer Helene Fischer and the pseudo-folk duo Wildecker Herzbuben, you would form a certain image of me – and probably not a positive one." This is greeted with laughter from the audience – nobody would seriously believe that the Max Planck Director really has such listening habits. Most people associate a liking for pop and folk music with low educational attainment and lower social strata. In contrast, classical music listeners tend to be viewed as educated and intelligent.

In addition to using a sociological approach to explain this phenomenon, it is also possible to use a psychological one. The idea behind the latter involves

» There are situations in which sophisticated German listeners find *Schlager* songs suitable and fun to listen to, but they would never put a checkmark next to this category in a survey of musical tastes

the linking of musical preferences with personality traits, as Paul Elvers, a doctoral student and academic staff member at the Max Planck Institute for Empirical Aesthetics, explains: "For example, there are studies that have tried to establish a link between sensation seeking and a preference for rock music. And that classical music and jazz fans, in contrast, tend to be associated with quiet or contemplative activities. The results of this research are mixed. Some studies show that such links exist, while others tend not to find any."

What is clearly proven, in contrast, is that, for most people, musical taste formed in childhood and youth remains a formative influence. Melanie Wald-Fuhrmann compares musical socialization with language acquisition. "It's like a musical mother tongue. Most people remain true to the musical taste of their childhood and youth because it's simply a lot of fun to engage with something that you know very well and can embed within your horizon of experience." However, it is also possible to observe that listening behavior can change with social advancement. That is how Wald-Fuhrmann explains why some people only discover classical music later on in life. "So you have 55-year-old CEOs who attend the Rheingau Music Festival and listen to a Handel oratorio despite having experienced a very different music socialization."

Melanie Wald-Fuhrmann heads the Music Department at the Max Planck Institute for Empirical Aesthetics. Her insights into musical taste also document social change.

At the Music Department of the Max Planck Institute for Empirical Aesthetics, such knowledge forms the basis for research projects that delve deeper into the causes of taste formation while at the same time aiming to analyze the variance in musical tastes. Melanie Wald-Fuhrmann and her colleagues are therefore seeking new answers to a very old problem that has preoccupied humanity since Plato and Aristotle – namely the basic question of aesthetics: what do people find beautiful and why? On the other hand, they can also be said to be working on a very current topic: the fundamental transformation our society has been undergoing for a good two decades – described by sociologists as a "second modernism" – and that is also reflected in music listening habits. The characteristics of this transformation include the globalization of the economy and culture, the loss of significance of traditions and social forms that are being replaced by an increasing diversity of lifestyles and values, and a constantly changing supply of education, culture, and goods and services, which is also driven by the Internet. This gives rise, in turn, to the phenomenon of individualization, meaning that each individual can and even must design his or her own life story and lifestyle in our pluralized society.

EXPERT LISTENERS AS MUSICAL OMNIVORES

But little research has been carried out on the change in musical tastes, and the data available on this phenomenon is sparse, regrets Wald-Fuhrmann. "Studies that began only in the 1990s, originating in the US, indicate that the hierarchical classification of music styles on the basis of social class is no longer valid. This appears to be particularly applicable to the social elites, who are increasingly including styles of music in their taste repertoires that are or were usually linked with connotations of middle or lower class tastes. People whose tastes reflect this phenomenon are described as omnivores: their tastes incorporate many styles of music – including very divergent ones."

To date, however, hardly any research studies have been carried out that document the change in musical taste in Europe, and specifically in Germany. Because of this, a current study published in the journal Frontiers In Psychology by Paul Elvers, together with two of his colleagues at the Max Planck Institute and a musicologist from the University of Vienna, is timely and relevant. The researchers evaluated the musical tastes of groups described as expert listeners and average listeners. Expert listeners, people who

Photo: Antje Pohsegger/MPI for Empirical Aesthetics

Musical taste brings people together: 75,000 heavy metal fans meet every August in Schleswig-Holstein at Wacken Open Air, the world's biggest heavy metal music festival.

Photo: Paul Ripke

engage professionally with music, are of particular interest for research on musical taste – and for the question as to whether their preference for a particular musical repertoire owes to their musical knowledge and training rather than their social origins.

Using an online survey, Paul Elvers collected data from around 1,000 students, a quarter of whom were studying musicology as a major or minor subject. The participants were requested, among other things, to specify how often they listened to pieces involving different styles of music. The frequency of their listening habits was divided into five levels ranging from "never" to "daily." A total of 22 musical styles were provided for selection, ranging from rock, pop and classical to punk, heavy metal and emo/screamo, to gospel, reggae and world music. In addition, the participants were asked to provide information about their social status, musical background and personality traits. When evaluating the survey data, Elvers used factor analysis to summarize the large number of musical styles in five categories: classical, jazz, house, folk and rock. He didn't simply investigate how often these categories are listened to by the experts and non-experts. Instead, irrespective of which of the two groups the listeners belonged to, he formed three sufficiently homogeneous clusters from the results: engaged listeners, ordinary listeners and rock listeners.

As the designation suggests, rock listeners are characterized by the fact that they listen to music from the rock and folk categories far more often than average, and to particularly little music from the classical and jazz repertoires. Ordinary listeners indicate that, in general, they listen to music only moderately often and tend to listen mainly to classical, house and pop. Engaged listeners, in contrast, listen to music considerably more often than the other groups, and display a clear preference for classical and jazz; however, they also frequently listen to folk and rock. Accordingly, the engaged listeners correspond more or less exactly to the phenomenon of the omnivore: they cover not only many different styles of music in their musical tastes – with a particular focus on sophisticated styles – but overall, they tend to listen to music intensively and often.

ROCK FANS – A GROUP APART

The central question for Paul Elvers is: How are these groups represented among the expert listeners and the control group? He discovered that half of the musicology students could be classified as engaged listeners. However, he also discovered that 36 percent of them were ordinary listeners, and 13 percent rock listeners. In the control group, in contrast, a normal (or Gaussian) distribution emerged: one quarter were engaged listeners, around half were ordinary listeners, and the remaining quarter were rock listeners. To explain why more of the students didn't display a preference for classical music in their listening habits, Elvers and Melanie Wald-Fuhrmann refer to the change in the subject of musicology in recent years. At the Humboldt-Universität zu Berlin, in particular, where the majority of the survey participants were recruited, pop and rock music are an in-

tegral component of musicology studies. Thus, the survey findings were largely in line with expectations in this regard.

Far more insightful for the researchers is the information provided by other aspects of the study, such as the fact that rock listeners formed a cluster of their own and classical fans displayed the greatest openness to different styles. "The fact that we discovered this tendency toward 'omnivorism' is the most striking difference between our study and earlier ones," says Paul Elvers. "It had already been established that people who study musicology have a preference for classical music. But the fact that they now also tend to engage with other styles is something completely new."

Another striking outcome of the study is that it failed to demonstrate any significant link between social status and musical taste. Of the surveyed students, around one-third came from the lower classes and lower-middle classes, a bit more than half from the middle classes, and 10 percent from the upper-middle classes. Thus, a broad cross-section of the population was represented: "The survey participants were young people," stresses Melanie Wald-Fuhrmann. "So it's entirely possible that their responses reflect a trend. And it would be a truly interesting development if musical taste is relinquishing its links with social identification." Elvers and Wald-Fuhrmann are aware that the study has its limits: based on their age alone, students don't represent the overall population. Moreover, it's possible that the students who come from lower social classes are already shifting toward a more elevated social status in terms of the orientation of their listening behavior.

THE RIGHT MUSIC AROUND THE CLOCK

Furthermore, there are differences between what people say in surveys and what they actually listen to. It is much easier to access very different types of

» Provide children with the experience of live music, let them play instruments, expose them to as much music as possible! Then everyone will have a key experience and perhaps find a style of music that becomes a truly great passion.«

Photo: fotolia

music today than ever before. Wherever they are, people can now access the right music to listen to day and night on their mobile devices. It's very possible that musical tastes and listening behaviors differ as a result of this, says Wald-Fuhrmann: "We choose to listen to very different pieces depending on our mood and activity. For example, there are situations in which sophisticated German listeners find *Schlager* songs suitable and fun to listen to, but they would never put a checkmark next to this category in a survey of musical tastes." The researchers are now attempting to pinpoint real listening behavior using the "experience sampling method," which documents the music people actually listen to. As a first step, the test subjects' musical taste is determined using a questionnaire. They then download an app to their cell phones to record what music they listen to and when they listen to it. In addition, they occasionally receive spontaneous requests to specify the situation they find themselves in: at home or out and about, jogging or in the subway, with friends in the park or at home in the kitchen washing dishes. Using the data obtained in this way, the researchers can compare the participants' musical tastes and situation-related behavior.

However, many questions remain open in relation to musical taste itself. The researchers are also working on new studies in this regard that will enable them to place the results in a broader context. "We would like to obtain a more multi-dimensional understanding of musical taste," says Wald-Fuhrmann, explaining their objectives. "To do this, we must ask not only about content, but also the range of musical tastes and the intensity of people's engagement with music. We want to understand the dependency on socialization and peers, and the ways in which people inform themselves about music and find out about new music. It is also interesting to establish, for example, what other family members are listening to."

A corresponding survey incorporating such criteria was recently posted on the website of the Max Planck Institute for Empirical Aesthetics. Anyone with an interest in music is invited to participate. To recruit participants, Melanie Wald-Fuhrmann's team is using a wide range of channels, such as ads in classical music magazines, social media, and groups that are organized in the context of music streaming services. It is also important for the taste researchers not only to survey a general framework of styles, but to differentiate between them in greater detail. Wald-Fuhrmann has identified another trend here: "The individual styles – whether classical or metal – are subdivided into numerous sub-styles. There are cases involving very dedicated fan groups of a sub-style that don't identify in the least with another sub-style. This is something that isn't always easy for outsiders to understand, but that is completely obvious and important to the individuals involved. In the area of classical music, for example, there is the type of fan who is interested in new music but who is completely different than the fan with a preference for Haydn and Beethoven, not to mention the fans of early music."

SUGGESTIONS FOR MUSICAL EDUCATION

Which factors are responsible for tastes within a given style being so widely divergent? And how does it happen that some people move away from the musical influence of their homes and families and develop a completely different taste in music? The psychological approach could be relevant here – in oth-

Classical music is traditionally considered to be the style of music favored by society's elite. However, this association is becoming increasingly tenuous – probably one of the reasons why audiences at classical music events are composed mainly of older people.

Musicologist Paul Elvers discovered his love of Johann Sebastian Bach at an early age while playing the piano. Such key musical experiences can have a long-term impact on musical taste.

er words, it's possible that personality traits play a role in musical taste.

Paul Elvers also examined this correlation in his study. His survey participants were asked to characterize themselves on the basis of the so-called Big Five personality traits – an established model in personality psychology. This involves the allocation of characteristics to five factors ranging between corresponding extremes: self-confident or sensitive, introverted or sociable, cautious or curious, careless or conscientious, and compassionate or detached. However, based on his findings, Elvers was able to establish only very weak links between personality and musical taste.

Melanie Wald-Fuhrmann has developed a different explanatory approach, according to which key musical experiences could play a central role in the shaping of taste. The musicologist is also collecting data for this research. "We are trying to establish, first, that it makes sense to introduce the construct of key experiences into the research on musical taste. To do this, we are underpinning it with autobiographical histories."

Histories like the one Paul Elvers can relate about himself: "My parents don't belong to the academic elite and didn't play classical music to me every morning. For example, my father was a big Pink Floyd fan and played music himself. That was my early experience. As a teenager, I discovered a love of classical music. I can remember one experience that had a particularly formative influence on me. When I started to learn the piano, at some stage I was able to play Bach's two-part inventions. And suddenly I understood this music. I understood the parts and everything fit together. It was a wonderful moment. I played this same invention repeatedly for two or three hours and was completely fascinated by it. Since then, Bach's music has been part of my repertoire and enabled me to gain access to that world."

Based on everything Wald-Fuhrmann has discovered up to now, playing music often triggers key experiences, as does hearing music live at a concert. An important role in this process is also played by people in the immediate environment who introduce young people to previously unknown music styles – for instance friends, teachers, relatives or trainers. "If you really wanted to," says the musicologist, "you could deduce suggestions for musical education from this: provide children with the experience of live music, let them play instruments – it doesn't have to be limited to classical music – expose them to as much music as possible so that an inner response is triggered! Then everyone will have a key experience. And that might result in people not having to content themselves with socialized musical taste, which may give them only an average fondness, but in being able to find a style of music that becomes a truly great passion.◂

Participants sought:
ww2.unipark.de/uc/Musikgeschmack

TO THE POINT

- **Musical taste is traditionally considered to be class-dependent: the elite listen to classical, the middle classes to sophisticated easy listening, and the lower classes to pop and folk.**
- **This categorization appears to be gradually disappearing. In particular, people who engage intensively with music are developing broader tastes.**
- **At the same time, it is possible to observe a strong fixation on sub-styles among many people, such as a preference for early music among classical music fans.**
- **Research is looking for factors that play a role in the formation of taste apart from social background, such as personality traits and key experiences.**

Photo: Felix Bernoully/MPI for Empirical Aesthetics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Making Music **with Muscles**

Thomas Fritz, Leader of the Music Evoked Brain Plasticity Research Group at the **Max Planck Institute for Human Cognitive and Brain Sciences** in Leipzig, knows how to make people happy and fearless – essentially as a kind of welcome side-effect. He conducts experiments using exercise machines with which you can create music. The experience of exercising with this equipment and simultaneously creating unique sounds not only reduces bodily exhaustion, it also puts the user in a good mood and lowers their anxiety and pain levels – effects that give rise to a range of therapeutic applications.

TEXT **STEFANIE REINBERGER**

Slaves used to sing on the cotton plantations of North America, as did convicts in quarries. Mariners belted out shanties at the top of their lungs to counter the wind and waves. Even today, soldiers sing cadence calls while marching, for extra motivation. And scientists from the Max Planck Institute for Human Cognitive and Brain Sciences in Leipzig use exercise machines to produce energizing rhythms and melodies. In search of a name for this new – and at first glance surprising – activity, they coined the label "Jymmin" – a cross between "jamming" and "gym."

Music makes physical exertion easier. That's why work songs have a long-standing tradition. It was previously assumed that singing songs while working serves to establish a regular beat that synchronizes the workflow and possibly also distracts the workers from the strenuousness of their labor. Yet Thomas Fritz, Leader of the Music Evoked Brain Plasticity Research Group at the Max Planck Institute for Human Cognitive and Brain Sciences in Leipzig, and professor for empirical music research at the Institute for Psychoacoustics and Electronic Music in Ghent, has arrived at a different conclusion. His studies with exercise machines that create music show that making music while doing a physical workout does in fact reduce the physical strain – at least with regard to strength training.

MAKING MUSIC IS SPORTIER THAN LISTENING TO MUSIC

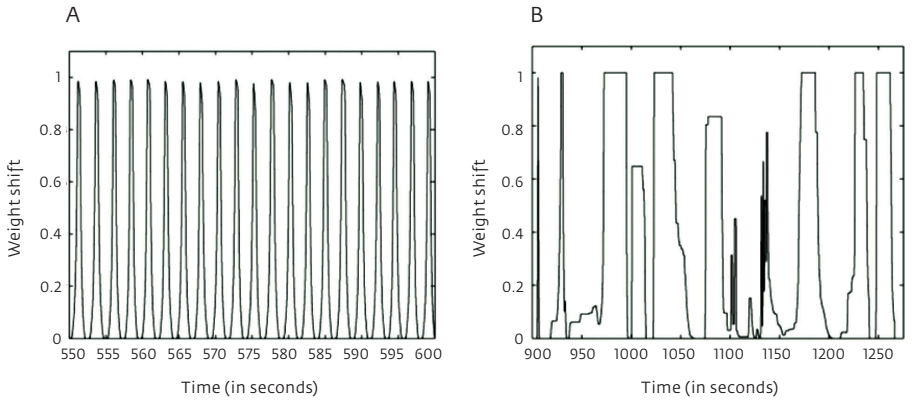
The experiment set up by the scientists in Leipzig involved 36 participants doing sports. None of them were musicians and none of them were professional athletes, in order to eliminate side-effects that could potentially distort the results. The first group of participants trained using conventional exercise machines – a stepper, a lat pull-down bar designed to strengthen the broad back muscle (latissimus) and an ab trainer – while listening to music, as in any normal gym. The second group, however, was allowed to use the Jymmin machines, meaning they made the music themselves.

The surprising result: Even though both groups completed the same exercise routine, the Jymmin group reported feeling a significantly lower level of physical exertion than the group using standard fitness equipment. Furthermore, physiological measurements of oxygen consumption and muscle tension showed that, during the Jymmin workout, muscles worked more efficiently and were also less tense. Fritz and his colleagues published this discovery in 2013 in the Proceedings of the National Academy of Sciences (PNAS), an American science journal.

When Thomas Fritz is asked how he came up with the idea of constructing fitness machines that produce music, he laughs and says: "That's a long story. Are you sure you want to hear it?" And then he gets talking. He recounts

Photo: Waltraud Grubitzsch

Inside the "gym" of the Max Planck Institute in Leipzig: While an assistant shows the participant how to correctly use the ab trainer, Tom Fritz prepares the computer that will record and visualize the movement patterns that result from the Jymmin composition program.



Stereotypical movement patterns that originate during conventional strength training result in even spikes in the graph depicting weight shift over time (diagram A), while movement that depends on music leads to a less stereotypical and physiologically more meaningful motor behavior with a greater degree of holding movements, creating an irregular line graph (diagram B).

his university studies in biology and his neuroscientific research. Around 15 years ago, while writing his university diploma thesis, he was already working at the Max Planck Institute for Human Cognitive and Brain Sciences in Leipzig, where he focused on the link between music and emotions – a topic that would continue to fascinate him throughout his career. "Basically, the first time I looked into how music triggers emotions was during my years at the university, when I had a part-time job composing my own live electronic music in the chill-out zones of clubs in Frankfurt and the surrounding region, often for ten or twelve hours at a stretch." He says this is when he observed how different sound parameters affected the mood of the party-goers.

However, the inspiration for Fritz' Jymmin machines came to him upon his return from an ethnomusicological research trip to the Mandara Mountains in northern Cameroon. As part of his doctoral thesis, the scientist studied how people who have never been exposed to Western music perceive it when they hear it for the first time. "In the beginning, nobody wanted to participate in my study, of course; after all, I was a stranger," Fritz remembers. "So instead, I took part in the music rituals of the Mafa." The Mafa, a particular ethnic group from northern Cameroon, form groups to play music using special flutes. Playing these instruments, Fritz reports, requires considerable physical effort, essentially a form of controlled hyperventilation that ultimately leads to a trance-like, euphoric state.

"I wanted people in our cultural sphere to be able to experience this same sense of euphoria," Tom Fritz explains. That's why he went in search of a method that would be more widely accepted in our part of the world – and that didn't require hyperventilation. "That shouldn't be underestimated. You'd always need a doctor present during the activity, just in case," he says. The scientist consequently began experimenting with exercise machines. He retrofitted standard fitness equipment so that it plays music when used – sometimes the music plays faster, sometimes slower, it swells and then subsides again, sometimes sequences are played to the end, other times they are cut up into staccato-like fragments. As a result, the person using the machine creates his or her own sounds and therefore feels, subjectively, like he or she is making music in a very expressive manner.

The Max Planck scientist produced the first prototypes of this equipment himself. "I basically always had a workshop wherever I went, and at that time I shared a studio with installation artist

Unlike conventional workouts, Jymmin systematically makes people subjectively feel positive sensations. There is a strong reciprocal effect between physical exercise and musical expression; the movements are indeed perceived as being arousing and beautiful.

Graphic: PNAS/Thomas Fritz; photos: MPI for Human Cognitive and Brain Sciences (bottom)

Tom Fritz uses magnetic resonance images to study which regions of the brain are influenced by Jymmin in the form of physiological changes. During the experiment, the participants listened to recordings of the music they themselves had composed.

Photo: Waltraud Grubitzsch

Carlo Crovato, who had great ideas regarding the mechanical aspects," says Fritz. The third member of this team of tinkerers was brain researcher John-Dylan Haynes, who today conducts research at the Bernstein Center for Computational Neuroscience in Berlin. Heeding the advice of the Max Planck Society, the three inventors applied for a patent. In the summer of 2014, Fritz put three of his sporty music machines on display at the German Hygiene Museum in Dresden as part of an exhibition called *Exploring the Now*. Of course visitors (15,000 in six weeks) were explicitly encouraged to try out the Jymmin equipment – much to their delight.

This story may sound a bit like Gyro Gearloose or a typical wacky inventor. Tom Fritz is accustomed to such reactions: "It might seem a bit strange, and when you see people making music with fitness equipment, that will likely take you by surprise at first," he admits. "But as soon as you sit on one of these machines yourself, it feels as if this is exactly what music was made for." It therefore comes as no surprise that the neuroscientist regularly uses his machines himself, as you can tell by his physique. "It's great for zoning out and relaxing the mind," he believes. Besides, the musical exercise machines have since become much more than merely the tinker project of a brilliant mind. The researcher began systematically studying the Jymmin effect. Fritz found out that Jymmin is not only less strenuous than exercise routines using conventional fitness machines – it also makes you happy.

EUPHORIA EXPERIENCE SIMILAR TO A TRANCE

Similar to the experiment on physical exertion, Fritz had his participants split up into two groups and do a workout. One group listened to music as they exercised, while the other group composed their own sounds. After the training session, all of the participants were asked about their experience. It turned out that the composer group was in a significantly better mood, and what's more, their mood remained positive for a longer period of time: The participants still felt happy during the second round of training, despite the fact that they were now only passively listening to the music. Moreover, further studies have shown that social interaction – a group of people can jointly create sounds using different Jymmin machines – further heightens the positive experience.

This brings Fritz another step closer to his goal of recreating the experiences he shared with the Mafa in Cameroon, but this time using Western methods – and under controlled conditions. "The link between strenuous physical labor and music originated long ago in the history of civilization. It is quite possibly as old as humanity itself," says Fritz. "Thanks to the Jymmin machines, sci-

What feelings does the same piece of music evoke in people from different cultural backgrounds? The field work that Tom Fritz conducted among the Mafa ethnic tribe in Cameroon several years ago was the starting point of his research into musical trance techniques that later inspired him to invent Jymmin.

entists will now, for the first time ever, be able to study this phenomenon in a laboratory. What we're doing here is what you might call a form of archeological psychology."

TREATING DEPRESSION AND ADDICTION WITH JYMMIN

Yet the neuroscientist believes Jymmin is more than just a great way to gain new historical-cultural and psychological insights: "Jymmin harbors vast potential for new clinical applications. The mood-lifting effect could possibly even become a useful element of depression therapy," Fritz believes.

Drug addicts undergoing treatment and rehabilitation could also benefit from the musical workout, as a further study carried out by the Leipzig-based scientists shows. "We were a bit concerned before conducting our experiment at the drug rehabilitation clinic, because some of the participants came to us straight after undergoing withdrawal. And whether patients with elevated levels of aggression should be doing strength training at all is a controversial issue, because the workout can potentially aggravate their aggressive behavior," the researcher explains. "We also weren't sure if the whole thing would backfire, because the euphorigenic effect could perhaps trigger a craving for substance abuse." His worries were unfounded: According to the psychological questionnaire the participants filled out afterwards, the craving sensations were, in fact, reduced after the workout. Moreover, the mood of the participants lifted, their sense of self-efficacy increased and they became more willing to be socially interactive – a key step in the drug rehabilitation process. The participants even felt that same positive effect of the workout one week later, when they participated in another experiment and this time merely listened to the music they had previously produced using the Jymmin machines.

The researchers in Leipzig are continually identifying new applications for their musical sports equipment. No wonder therapy centers have started showing an interest in this peculiar invention. A study that is currently underway has indicated, for example, that patients suffering from pain could also strongly benefit during rehabilitation. Jymmin reduces the participants' pain sensitivity during exercise, which is crucial to most rehabilitation therapies, as many patients from very different backgrounds feel pain when doing therapeutic exercises. Furthermore, Jymmin appears to reduce anxiety in people suffering from chronic pain. The levels of

Photo: Ildiko Hetesi

» When you watch people doing a Jymmin workout, you will be pretty surprised at first. But as soon as you try it out for yourself, it feels as if this is exactly what music was made for.«

anxiety are often significantly elevated in these types of patients, as they are in patients who suffer from Alzheimer's or who are recovering from a stroke. "By reducing the amount of anxiety these people feel, it could be possible to substantially improve their quality of life," says Fritz. And there's more: Anxiety and depression significantly enhance an individual's risk of suffering (another) stroke, which in turn is detrimental to their mood and quality of life, increasing the stroke risk. Jymmin, the scientist believes, could help patients break out of this vicious cycle.

UNDERLYING MECHANISMS REMAIN UNCLEAR

It almost appears as if Fritz and his colleagues have discovered some type of panacea. So far, however, no one is able to say with certainty which mechanisms underlie Jymmin's ability to influence mood levels, addictive behavior and pain. The Music Evoked Brain Plasticity Research Group has set itself the task of finding an answer to this pressing question. Hormones and endorphins could play a role, Fritz suspects. And recently, the first immunological studies carried out showed that the number of monocytes – special white blood cells and key players in the body's immune system – increased considerably one hour after the Jymmin workout. This would indicate that the musical workout bolsters the body's own defenses.

Furthermore, the scientists from Leipzig have initiated a first series of studies involving imaging technology, because one thing is certain: the brain plays an important role in the Jymmin effect. It has been common knowledge for quite some time that music and movement are closely linked in our thinking organ – a relationship researchers call auditory-motor mapping. Someone who knows how to play the piano, for example, would need only to listen to a recording of a piano concert in order for the motor cortex regions responsible for hand and finger movements to be activated. The brain is essentially playing along in spirit, even when the person is not actually moving their fingers. In the case of professional musicians, the activation of the respective regions in the brain is virtually identical when playing and when listening to music. Yet a similar effect can even be observed in people who don't actively make music. Studies conducted by Tom Fritz several years ago using magnetic resonance imaging showed that, in participants who were listening to pleasant music, regions of what is known as the Rolandic operculum were active – a region that represents the larynx and vocal cords, among others. This means that the brain possibly "vocalized and sang along" in spirit.

Fritz hopes to be able to use his Jymmin machines to recreate this effect. First of all, he believes that the feedback loop linking movement and music reinforces the training effect. The movement patterns are essentially etched deeper into the brain. And secondly, due to the fact that this leads to stronger mapping, you could assume that the patients – basically between the actual workout sessions – feel the same therapeutic benefits just by passively listening to their own Jymmin compositions. With the help of modern imaging technology, Fritz aims to find out if his hypothesis will prove true.

The way the Leipzig-based researcher sees it, his research into the Jymmin effects are still in the very early stages. He hopes to gain further fundamental insights by using Jymmin machines as part of a longer course of treatment. Can regular workouts be used as a preventive medical measure to counter the development of depression-related symptoms, for example? In search of answers to questions such as this, starting in January 2016, Fritz plans to set up a workout space where anyone who is interested will have the opportunity to regularly take part in Jymmin training sessions. That means even more energizing beats will be created in Leipzig – in the name of science and for treatment methods of the future. ◂

TO THE POINT

- **For centuries it has been common knowledge that music in the form of work songs makes physical labor feel less strenuous. Now, with the help of music produced using specially equipped exercise machines, scientists are able to prove that music does in fact reduce perceived exhaustion. This new type of strength training is called "Jymmin."**
- **Jymmin significantly lifts a person's mood, and this effect can be further enhanced by means of interaction when creating the sounds. The training can be used for therapeutic purposes: drug addicts in rehabilitation experience euphorigenic effects without the cravings, and in chronic pain patients, Jymmin reduces anxiety after exercise. Some of these effects are even detectable when the patients passively listen to music they composed in a previous workout session.**
- **Magnetic resonance images of the brains of participants show that brain regions that are responsible for the larynx and vocal cords are active while they are listening to music, meaning the brain is possibly "singing along."**

The Musical Score of Emotions

Music arouses emotions. But exactly what people feel when listening to a piece of music and how they express these feelings is influenced mainly by the times they live in and their culture. A research group led by **Sven Oliver Müller** at the **Max Planck Institute for Human Development** in Berlin has carried out research on the changing emotions in Europe's musical life, focusing in particular on the impact of music's communal spirit.

TEXT **PETRA MIES**

Photo: Corbis

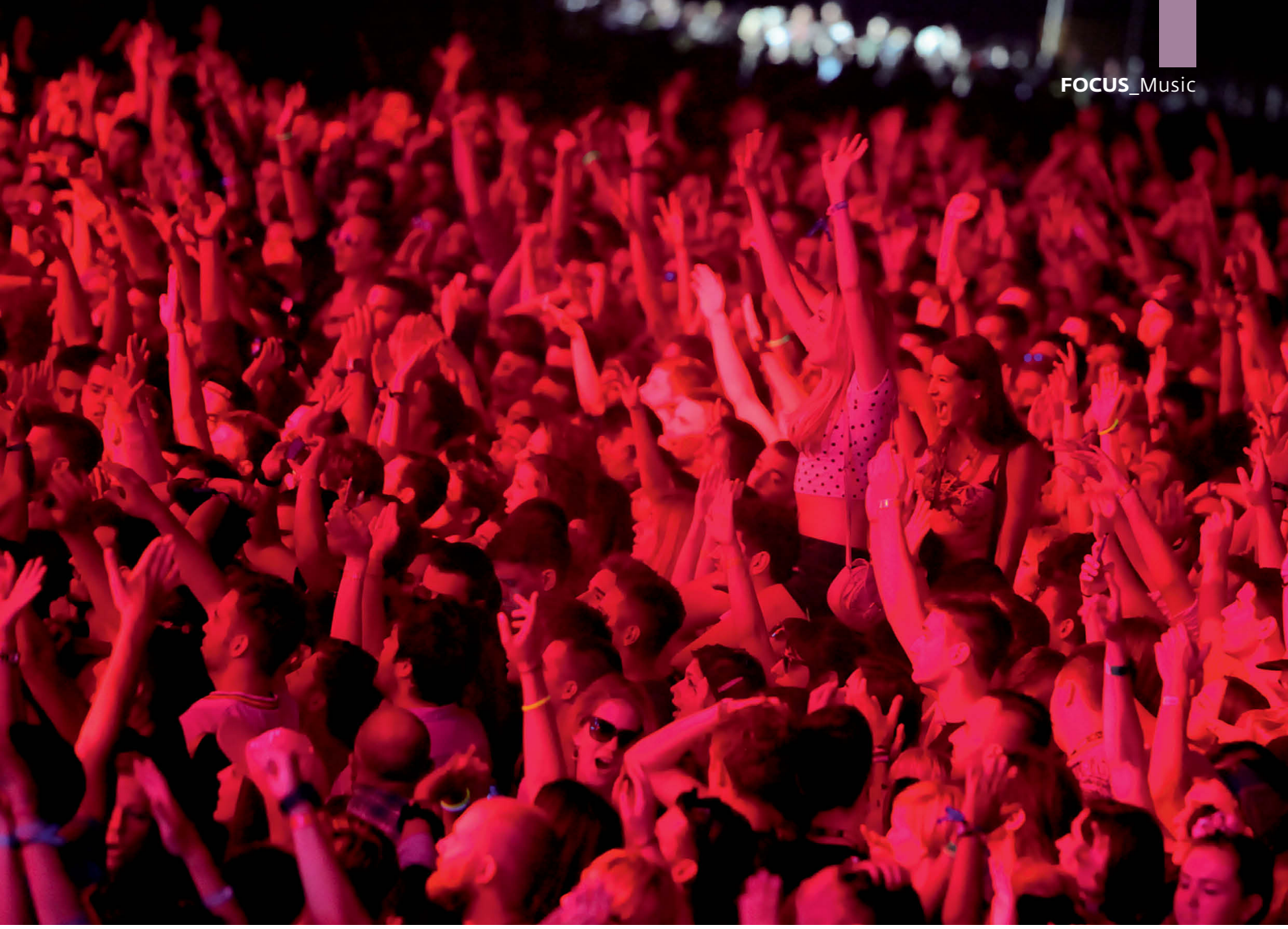


Photo: Aleksandar Kamasi/Shutterstock.com

Reverent silence or loud enthusiasm: The behavior of an audience is influenced by the culture, time and environment.

Uncle Martin, who is in his late 40s, wants to give his nephew Niklas, who recently turned 16, a treat. "It will be fantastic," announces the older man. "I managed to get hold of tickets for the Simple Minds concert, they are amazing. We can go together." His nephew looks puzzled. "Simple Minds? Do they actually still perform?" The boy knows little or nothing about the Scottish band that has been one of his uncle's musical icons since his teenage years. His uncle rummages around, shows him records, CDs and photo albums, plays him songs, revels in the music and tells him stories about things that happened back then. "Here, look, here I am with my friends Michi and Klaus, it was crazy."

Will Martin and Niklas experience similar feelings in the crowd when they attend the concert in Berlin's Tempodrom arena in November? Will the nephew respond in a similar way to his uncle who, like so many others in the audience, will remember the 1980s and the rebellious mood of his youth?

EMOTIONS AND THE CHANGING TIMES

Anna, 14 years old, and her great grandmother, who will soon be 90, have very different concert plans. "The Berlin Philharmonic!" cries the old lady again and again. "Beethoven's Fourth and Seventh! I heard them when Wilhelm Furtwängler was still principal conductor, and Karajan too! Those were such great times," says Henriette, and starts telling stories from her long life. Anna, who is thinking about the fact that she once again hasn't practiced the piano, is looking forward to spending the evening with her beloved great-grandma. But she's not sure if Beethoven, played in the stiff atmosphere of the Berliner Philarmonie, will move her in a similar way to the wild concert by German rapper Cro she recently attended with her friends.

A rock party mood in one instance and sublime-tasteful classical music in the other – when it comes to the experience of music, contrasting emotions compete.

What do people feel when they hear the same thing in public with others? >

» The function assumed by brass band music, workers' anthems and pop tunes at such major events shouldn't be underestimated. They don't serve the purpose of individual listening pleasure, but the "we feeling."

Does everything sound equally joyful to everyone because the composer composed a certain passage of the piece in a particular way, or simply sad in other places? And what influences people's response in the process? Do their environment, era and education play a role? How, when and why do groups form in society through musical practices? How important are shared interests, friendships and enmities? And to what extent did emotions in Europe change over the course of the 19th and 20th centuries, and where do the continuities lie?

These are the questions explored by the scientists working on the *Felt Communities? Emotions in European Music Performances* research project. The project started five years ago and at its high-point involved almost 20 doctoral students, postdoc fellows, academic staff members and assistants. The project is due to conclude with a workshop on the history of emotions and music, as well as further future research perspectives.

DANCING AUDIENCES, VIRTUOSO CONDUCTORS

Historian and Research Group Leader Sven Oliver Müller sees the question as to whether and how music, education and emotions are linked as "a fascinating topic in which all the answers inspire more curiosity about other questions."

According to Müller, this topic cannot be considered in isolation from the relevant social and cultural background, historical situation, societal discourses, and social practices. "The relationship between music and emotions is constituted not only by man and sound, but also by the body and knowledge, taste and communities."

Music is the language of feelings. A platitude, perhaps. But according to Müller, the fact that these emotions are also shaped by learned musical and non-musical experiences and taste patterns and, above all, by shared listening, creates "complex textures." These include dancing concert goers as well as the performances led by virtuoso conductors.

In order to investigate these phenomena, the research group studied a huge number of sources. It scrutinized audio and visual documents, music critiques, fan publications, diaries, letters, memorabilia, and merchandising products. Music is ultimately only all of these things combined.

Whether concert audiences scream or are so silent that every little cough represents an unpleasant interruption, or whether music triggers a profound happiness in them or makes them aggressive is not, in any way, grounded in their individuality. As the 46-year-old historian explains, it is only through the interplay of zeitgeist, education and emotions that the codes of musical practices arise and enable us to understand how people perceive them. Communication in musical life fulfils four ideal-type functions: "It serves the purposes of information, opinion formation, socialization and entertainment."

The extent to which it can create and threaten communities is often underestimated. One need only think of political party conferences, whose media perception is dominated more by strong television images than musical associations. Nevertheless, the function assumed by brass band music, workers' anthems and pop tunes at such large-scale events shouldn't be underestimated. They don't serve the purpose of individual listening pleasure, but the generation of a "we feeling." Music can hold a group together and direct it in a subtle way.

EXPOSURE TO HARD ROCK AS A TORTURE METHOD

But it can also exert strong control. As far back as the world wars, occupying powers used music as part of their occupation strategy, and music also served as a propaganda tool and source of resistance. Depending on the circumstances, music was intended to humiliate, encourage and even torture those who heard it. Wars that involve the use of music and the associated emotions continue to the present day. For example, in 2004 the US military made use of not only bombers but also aggressive music in the Iraqi city of Falluja, which became established as a rebel stronghold under the American occupation. Giant speakers bombarded the rebels with the music of hard rock bands Metallica and AC/DC. And, according to Müller, this is not the only example of "music being used on a martial basis to exercise force and power over the human mind and body."

In her seminars, Marie Louise Herzfeld-Schild repeatedly draws attention to the fact that the emotional impact of

Fostering community: Musical interludes have a permanent place at political party conferences. Newly elected party chairman Matthias Platzeck (middle) joined in the performance of the miners' choir at the SPD party conference in 2005.

Photo: dpa Picture-Alliance

music is particularly strong when it is experienced in a group. "I show the students that even soft historical factors in this cultural context enable well-founded statements to be made about society," explains the philosopher, who holds a doctorate in musicology. If you only examine how the body reacts to certain musical phrases, if you only measure brain flows without considering the definition of music and its reception and social-aesthetic context, it is practically impossible to understand the emotional state of an era or group. "The concept of music involved here is very broad," stresses the 33-year-old researcher.

This macro-understanding constantly prompted the Max Planck research team to work on an interdisciplinary basis and to draw on different disciplines. Research technology assistant Iris Törmer reports how, during the project, historians, sociologists, musicologists and even anthropologists jointly investigated the auditory experience in Europe over the last two centuries.

THE SOCIOLOGICAL POWER OF MUSICAL SOUNDS

Neurologists and psychologists also came to a summer school held in Berlin two years ago to participate in an unusual forum involving disciplines that usually tend to work on a separate basis. Müller fondly remembers how productive it was to discuss different methodological approaches and combine them whenever possible. "Needless to say, we didn't succeed in reducing everything to a generally applicable formula along the lines of 'four bars of Sibelius make people sadder than eight bars of Mozart'." However, despite the broad nature of the topic, they succeeded in providing a clearer picture of the sociological power of musical sounds.

"In our team, with its accumulated specialist knowledge, 'change' was always the connecting and key concept for our work," adds Müller. "The forms of musical emotions that were experienced at a Roman opera or religious service in 1810 are not identical to those experienced at a punk concert in Liverpool in 1997."

To put it succinctly, collective emotions during the experience of music also have their fashions, and the way they should be assessed within their specific context also changes. By way of example of these emotional concepts and the changes they undergo, Marie

Breathtaking: In the 1840s Franz Liszt captivated audiences with his virtuoso piano playing. Women often fainted at his performances.

Louise Herzfeld-Schild refers to national pride: "This was acted out intensively in Germany in the 19th century but is considered problematic today," she says. "In contrast, this emotion is viewed completely differently in France and America, even today."

The researchers emphasize that many pointers to emotions that are typical of a given era can be found in the history of music. When celebrated musician Franz Liszt performed in the 1840s, women fainted by the dozen and euphoric audience members tussled for the handkerchiefs he had used to dab his brow. Such extrovert behavior would be unthinkable in today's concert halls, where the dictum of profound contemplation prevails. Quiet please: devout attention and silence are the order of the day.

The history of opera doesn't have any standard code of behavior to offer, either. In Mozart's day, 250 years ago, eating, drinking and loudly conversing during performances caused no offence. Today, such behavior would be considered a serious faux pas. It is simply not done.

DIFFICULTY IN SEARCHING FOR SOURCES

"We assume that emotions are learned practices," explains Marie Louise Herzfeld-Schild. She researched hymns of the 18th and 19th centuries. "What was sung and not sung before and after the Enlightenment tells us a lot about spiritual states of mind." Feelings are in no way exclusively internal states that unfold independently of people's environment. The external influence flows inwards and is then expressed publicly."

But it isn't always easy to find proof of this. Even if, according to Müller, "almost every source is ultimately relevant, the search for sources in letters, newspaper articles, images, song books and treatises is more of a challenge in periods before the availability of recording media and the proliferation of such media right up to the Internet. Moreover, the sources must be evaluated correctly.

Marie Louise Herzfeld-Schild draws attention to the fact that letters were not always as personal as they are today. "The authors of travel letters in the 18th century assumed that these would be read aloud in a wider context at a later point in time. For this reason, such letters were more likely to reflect soci-

Photo: Wikipedia/public domain

» Feelings are in no way exclusively internal states that unfold independently of people's environment. The external influence flows inwards and is then expressed publicly.

etal norms." Should feelings be mentioned at all, they must be noted.

Moreover, the meaning of words themselves also changed. For example, around 1900, honor was perceived as an elite and noble emotion; after the 1950s, it tended to be associated with more negative connotations. "Semantics, vocabulary and emotional knowledge are themselves subject to constant change," observes the scientist. "There are times in which crying is fashionable, and phases when it is just the opposite."

Müller refers to how emotional life is also socially conditioned and influenced by zeitgeist. "In the period around 1930, people didn't care to see crying men, and this had a huge impact on behavior at the time." If the group pressure is as great as the fear of being ridiculous, feelings adapt to the collective. "Rational decisions can be highly emotional."

A HISTORY OF HATE AND DEVOTION

The historian refers to the varied reception of opera and concert performances in the 19th century. "The changes in taste and listening behavior provide a good indicator of how aristocratic and bourgeois codes of perception changed," he says. "The reception of Wagner in Germany alone from that time to the present day contains so much material that it enables us to understand the change in musical communication as a history of hate and devotion." Moreover, it proves the possibilities for interpretation and action offered by the work of a single composer in the historical and sociological context. "The spectrum of emotional practices is vast." There is no causality between a certain piece of music and its emotional impact.

Müller also draws attention to the fact that emotions can be "strategically deployed and infectious. I do not believe in a clear divide between reason and emotion. This classic opposition is irrelevant." What is involved instead is a spiral, whose mechanism can delight or soothe a group, or affect it in a different way.

The approaches used in emotion research are particularly helpful in the current era of globalization. Müller refers to the emotional significance of music and instruments for ethnic and religious minorities, for example. His colleague Herzfeld-Schild adds: "The more accurate identification of how particular emotions are shaped in particular cultures could be useful for international cooperation."

According to Müller, insights that serve future needs can be gained not only from the analysis of contemporary sensitivities, but also those of past eras: The analysis of how and why – apart from the obvious reasons – the demonstrating rock fans and youth groups of the 1960s differ from Wagner fans in Bayreuth could provide fundamental insights into the political situation in the Federal Republic of Germany and current cultural movements. The historical analysis of musical emotional worlds and music as a factor in political rule is, therefore, relevant to our future coexistence.

Moreover, as Marie Louise Herzfeld-Schild explains, we already make use of the history of emotional reception that every piece of music carries in many situations. This happens both consciously and unconsciously. "The best examples of this are national anthems." Everyone knows them and they unite complete strangers in soccer stadiums.

ADVERTISING JINGLES SUGGEST STRENGTH AND HAPPINESS

Sounds and the group emotional code that accompanies them are also naturally of interest to advertising. "It aims to profit from the learned emotional connections generated by certain pieces of music," says Müller. And it is able to do this only because the target groups have learned and experienced feeling as desired. Even if it all happens on an unconscious level, potential customers are intended to perceive the advertised product as something that makes them strong and free, and in the best case, even completely happy.

The researchers established how radically emotional musical practices can change and that, despite their idiosyncrasies, people are always products of their time, education and origins. What the Romantic audience saw as a true expression of the soul may have been perceived in a completely different way by subsequent generations. Something that may seem deeply moving and arousing today can appear altogether more cheerful tomorrow. >

Multimedia: Sven Oliver Müller and Marie Louise Herzfeld-Schild avail of a very wide variety of sources in their research – from sound recordings and posters to merchandising products.

Existing or fervently desired belonging to a particular community is also important here, although the image of the latter can change as radically as the reception patterns of certain pieces of music. Marie Louise Herzfeld-Schild refers to Theodor W. Adorno's typology of listeners of 1962, which is not entirely unproblematic from today's perspective. Adorno differentiated between, among others, the expert listener, the good listener, the culture consumer, the resentment listener, the entertainment listener and "the rest." Of course, he was defining ideal types here, and hybrid forms are the norm in reality.

Müller reports on an experiment carried out by the Westdeutsche Rundfunk (WDR) broadcasting company in 1977, which remains interesting and relevant today. In the experiment, 563 test subjects were asked to compare the last movement climax of three different interpretations of Anton Bruckner's Fourth Symphony by Karl Böhm, Leonard Bernstein and Herbert von Karajan. The listeners were supposed to try to match the recordings with the individual conductor, or at least indicate the differences they were able to identify between them. "The self-identified connoisseurs from the educated classes, in particular, followed the cult of the conductor in vogue at the time and explained the different interpretations in great detail with the help of their acquired taste in music," explains the Research Group Leader. The representatives of the white collar and working classes, who accounted for almost 20 percent of the group and had no acquired expert knowledge, were unable to identify any differences between the three versions. Müller laughs. "They were right: the WDR had played the same recording to all of the test listeners three times." ◀

TO THE POINT

- **How people experience music depends strongly on the historical context, habits and fashions, as well as on their social origins and education.**
- **When people listen to music together, the group influences the individual listening experience.**
- **Music can be used to intensify the "we feeling" and direct a group, but it can also be used to exclude and even torture.**

Photo: Norbert Michalke

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An Addition to the Human Family

Scientists have discovered the fossilized remains of a previously unknown human species in a cave in South Africa

The human genealogical line has long since become more of a bush than a tree. It's easy to lose track owing to the sheer number of branches. And now another member, known as *Homo naledi*, has been added. An international team of researchers including scientists from the Max Planck Institute for Evolutionary Anthropology in Leipzig discovered well over a thousand bones of at least 15 individuals in a South African cave and attributed them to a previously unknown human species. *Homo naledi* was around 1.5 meters tall and weighed 45 kilograms with a brain the size of an orange. Several characteristics of its skull and teeth show that it was one of the early members of the human genus. The researchers don't yet know precisely when *Homo naledi* lived. Although it was able to use tools with its hands, the extremely curved fingers indicate that *Homo naledi* – "naledi" means star in the local language – possessed climbing capabilities. It was also an able walker, as its feet are virtually indistinguishable from those of modern humans, and it had long legs. Its shoulders, however, are more similar to those of apes. This combination of primitive and modern features distinguishes it from any previously known species. The researchers discovered the bones deep in the caves, in a chamber that is connected to the rest of the underground system only by a 20-centimeter wide crevasse. The site of the find has led researchers to conclude that *Homo naledi* may have intentionally disposed of its dead in this inaccessible place. (eLIFE, September 10, 2015)

The modeled head of *Homo naledi*. It took around 700 hours of work to reconstruct the head from the skeletal remains. (Image from the October issue of National Geographic)

Stem Cells for a Larger Brain

A single key gene changes production of nerve cells in the neocortex

With its grooves and bumps, the surface of the human brain resembles a walnut. This exterior is the result of a lack of space: over the course of evolution, the cerebral cortex – and in particular the neocortex – has grown to such an extent that it only fits into the skull when folded. However, the human neocortex isn't just larger; it also contains more nerve cells than that of other mammals. These nerve cells are formed by progenitor cells during embryonic development. In humans and monkeys, they divide multiple times, thus producing a large number of nerve cells, whereas in mice, for instance, they divide only once. The neocortex of mice therefore remains smaller. Scientists from the Max Planck Institute of Molecular Cell Biology and Genetics in Dresden have now adapted the activity of a regulator gene in a particular group of progenitor cells in the mouse brain to activity in the human brain. These progenitor cells also produced more nerve cells in the brains of rodents and created the conditions for a larger brain. The activity of an individual key gene can therefore have a significant influence on brain size. (PLOS Biology, August 6, 2015)

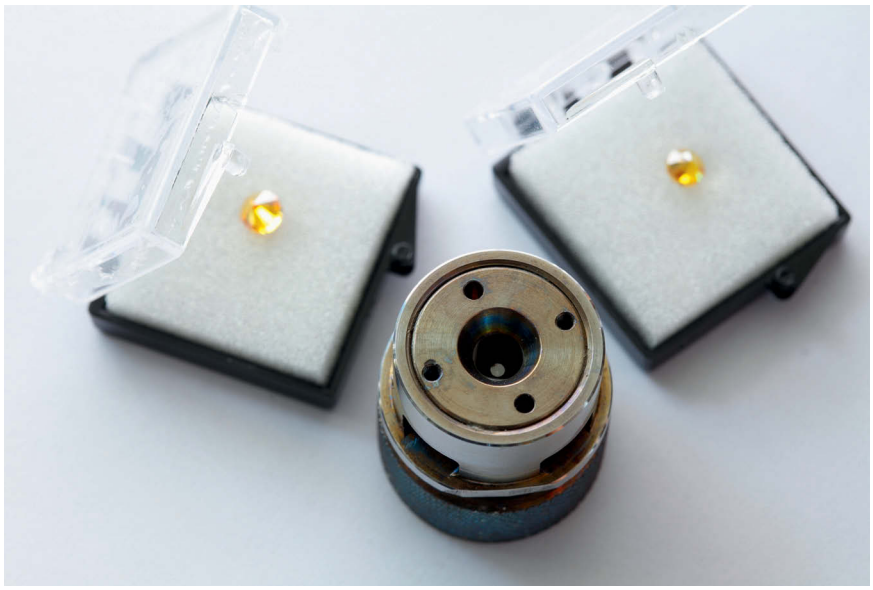
Cross section of a mouse brain: In the neocortex of a genetically modified mouse (right), the Pax6 regulator gene is more active than in normal mice (left), with similar activity to that in humans. These animals possess more progenitor cells with active Pax6 (red).

Photos: Mark Thiessen/National Geographic (top), MPI of Molecular Cell Biology and Genetics (bottom)

No Resistance at Record Temperatures

Hydrogen sulfide becomes superconductive under high pressure at minus 70 degrees Celsius

No material has previously been able to conduct current without resistance at such a relatively high temperature. Researchers at the Max Planck Institute for Chemistry in Mainz and the Johannes Gutenberg University Mainz observed that hydrogen sulfide becomes superconductive at minus 70 degrees Celsius when the substance is placed under a pressure of 1.5 million bar. This corresponds to half of the pressure of the Earth's core. With their high-pressure experiments, not only have the researchers in Mainz thus set a new record for high-temperature superconductivity, but their findings have also given fresh impetus to the search for materials that transport current at room temperature with no loss. Such superconductors could be found among hydrogen-rich compounds that might possibly even lose their resistance at a much lower pressure. (Nature, August 17, 2015)



Amazingly handy: The apparatus that the team at the Max Planck Institute for Chemistry used to generate extremely high pressures. In the center are two diamonds between which the sample is compressed.

Cancer Drug Prolongs Life in Flies

Trametinib inhibits the same signal pathway in flies and humans and could therefore conceivably also work on us

Humans, yeasts and fruit flies began to evolve separately millions of years ago, but their cellular processes are nevertheless often similar. One example is the Ras-Erk-ETS signal pathway. This controls cell division and cell death in all three organisms. Overactivation of the signal protein Ras can turn healthy cells into cancerous ones – also in humans. The Ras protein has mutated in around one-third of cancer patients. Cancer drugs such as Trametinib are deployed here and halt tumor growth. Scientists from the Max Planck Institute for Biology of Ageing in Cologne have now discovered that Trametinib extends the life of fruit flies by 12 percent. When the researchers administer the active substance to older flies, their life expectancy is still increased by 7 percent. The researchers observed no adverse effects on the insects' digestive system or food intake. As human cells contain the same molecular switches for the effect of Trametinib, the cancer drug could, in the future, conceivably also be used as an anti-aging drug. (Cell, June 25, 2015)

A fruit fly in old age. Drugs that extend the life of flies could also increase human life expectancy.

Photos: Thomas Hartmann (top), Nazif Alic (bottom)

Turbines Lessen Wind Energy

Large wind farms with a high density of installed capacity slow down the wind and generate less electricity than previously thought

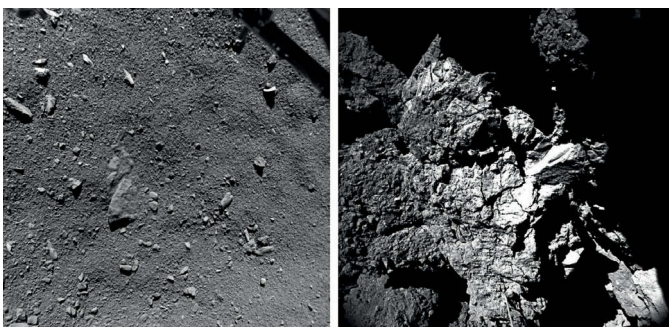
Less energy can be harnessed from the wind than was previously assumed. For example, a 2013 study by the German Federal Environmental Agency concluded that almost seven watts of electrical power per square meter could be generated from wind energy. However, an international research team headed by scientists from the Max Planck Institute for Biogeochemistry in Jena has now shown that the rate is significantly lower. The researchers calculated for the state of Kansas, USA, that a maximum of 1.1 watts of electricity could be generated per square meter. The correlation between the amount of energy generated and the number of wind turbines isn't linear, as more turbines slow down the wind. This is particularly noticeable with very high turbine density. The effect occurs everywhere. The amount of electricity actually generated by wind power varies slightly from one region to another. In Kansas, a lot more wind energy could be used efficiently. However, it is unlikely that it would be feasible to exploit the wind energy potential the Federal Environmental Agency identified in Germany. (Proceedings of the National Academy of Sciences, August 24, 2015)

Expandable only to a limited extent: Wind parks such as this one at Smoky Hills Wind Farm in Kansas, USA.

Messages from the Surface

The measurements recorded by the *Philae* lander on Churyumov-Gerasimenko deliver initial results

The surface dust of the comet 67P/Churyumov-Gerasimenko contains a wide variety of organic molecules. A team of scientists led by the Max Planck Institute for Solar System Research in Göttingen has detected no fewer than 16 compounds. To accomplish this, they used the COSAC instrument aboard *Philae*, which recorded the data shortly after first touching down on the comet on November 12, 2014. Many of the substances are considered to be key molecules for biochemical reactions, such as alcohols, amines and nitriles, which have already been discovered in the gas clouds of various comets; but methyl isocyanate, acetone, propanol and acetamide were also found. The majority of the molecules contain nitrogen, but carbon dioxide and ammonia weren't present. New data from *Philae* also indicates that the first landing site, Agilkia, is covered by a layer of dust around 20 centimeters thick whose pressure resistance is comparable to that of freshly fallen snow. The firmness of its final landing site, Abydos, in contrast, was two thousand times higher. (Science, July 31, 2015)



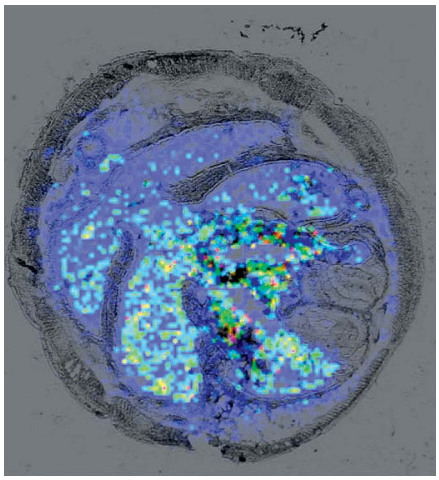
One soft and one hard landing: The left-hand image of the Agilkia landing site was taken using the ROLIS camera from a distance of nine meters, shortly before *Philae* touched down on the comet's surface.

The right-hand image of the final landing site, Abydos, was taken by the CIVA camera on November 13, 2014.

Earthworms Decontaminate Their Food

Worms' antibodies enable them to decompose billions of tons of foliage each year

Up to 300 earthworms live in an area of one square meter. They feed on dead organic matter that provides them with the nutrients they need to survive. But the worms must also protect themselves against toxic organic substances. They succeed in doing so thanks to drilodefensins in their intestines, as researchers at the Max Planck Institute for Marine Microbiology in Bremen discovered. The more toxins found in the worms' food, the more this protective substance forms in their intestines. These molecules coat the food proteins and digestive enzymes in the intestines, preventing the plant toxins from attaching to them. The drilodefensins appear to be extremely useful to the worms, as they recycle the substances several times. (Nature Communications, August 4, 2015)



Cross section of an earthworm. Substances that protect against toxic organic residue (light blue to red) accumulate in the intestines (dark blue).

Repetition Yields Negative Results

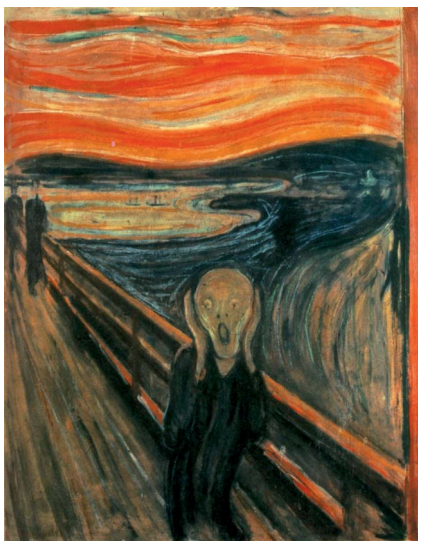
Open Science project attempts to verify 100 psychology studies

How well can psychological studies be reproduced? This question was addressed by an international team of around 300 researchers, including four scientists working with Susann Fiedler at the Max Planck Institute for Research on Collective Goods. Using the Open Science Framework web platform, they compiled data for the reproduction of 100 research studies that were published in 2008 in three prestigious journals. Less than half of the repeated tests produced the same results originally achieved, regardless of the analytical method used. The team emphasized that failure to achieve individual replications didn't necessarily indicate that the original findings were incorrect. Rather, it should be understood that small changes in the context or in the research conditions may have remained undetected despite being of fundamental importance to the achievement of the results. Susann Fiedler also welcomed the fact that science is actively analyzing itself and starting to undertake corrective action to improve the quality and efficiency of the research process. The established incentive system, however, still predominantly rewards the publication of new and surprising research results. (Science, August 28, 2015)

Alarm Signal for the Brain

Acoustic niche ensures impact of screams

Anyone can differentiate a scream from all other sounds, and is put on alert by it. David Poeppel from the Max Planck Institute for Empirical Aesthetics, together with colleagues from New York University and the University of Geneva, have examined why this is the case. The researchers determined that screams have a trait called "roughness." Sounds obtain a temporal structure due to change of amplitude or frequency. When these changes happen very quickly, the ear is no longer able to "break down" these temporal changes – such sounds are then perceived as rough and therefore unpleasant. In this way, screams activate the region of the brain used for processing and remembering fear. (Current Biology, July 16, 2015)



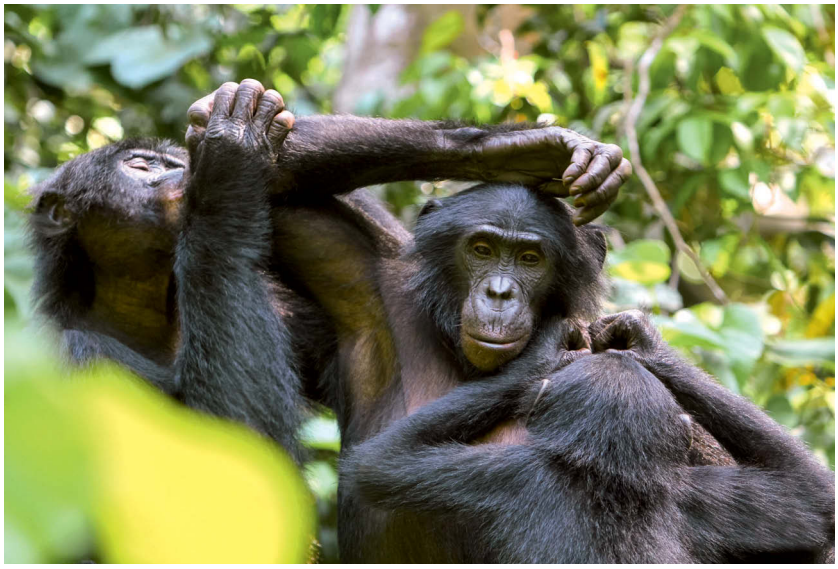
"The Scream" by Norwegian artist Edvard Munch is one of the world's most famous paintings.

Photos: Manuel Liebeke (top), in the public domain (bottom)

How About Getting Together?

Female bonobos communicate their intentions using pointing and pantomime

Humans can describe objects, people and processes through facial expressions and gestures. Such symbolic understanding is a significant part of human communication. Researchers at the Max Planck Institute for Evolutionary Anthropology in Leipzig have observed that bonobos can also communicate in this way. To solve conflicts, female bonobos invite other females to engage in socio-sexual behavior by using pointing gestures and mimicking hip swings, thus peacefully defusing potential conflicts. Sexual contact with other females plays a special role in the process. The observations revealed that the females emphasize a need for physical closeness through pointing and an unmistakable hip swing. The action is performed, as it were, in pantomime. Humans also use similar gestures. Sexual relations in humans were perhaps the motivating force for more complex forms of communication, as gestures and facial expressions play an extremely important role here. (Scientific Reports, September 11, 2015)

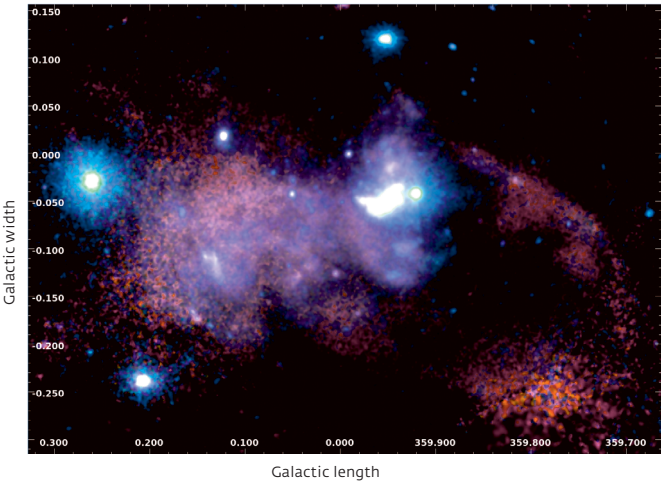


Social interaction among bonobos: The animals also communicate through pointing and pantomime.

The Turbulent Heart of the Milky Way

Using X-ray light, astronomers observe the events around the black hole at the center of our galaxy

Researchers from the Max Planck Institute for Extraterrestrial Physics used the X-ray satellite *XMM-Newton* to X-ray the heart of the galaxy. The best map of the region produced to date shows a pair of bipolar lobes that extend tens of light-years above and beyond the galactic plane and that are centered on the location of the supermassive black hole that is presumed to exist there. Matter and energy in the gas lobes apparently come from three possible sources: outflows from very near the event horizon of the black hole; winds from massive stars orbiting the hole; and catastrophic events associated with the death of massive stars close to it. The team also discovered fingerprints of warm plasma in the outskirts of the region depicted on the map. The processes at the heart of the Milky Way evidently have an impact that extends far beyond this central region. (Monthly Notices of the Royal Astronomical Society, August 20, 2015)



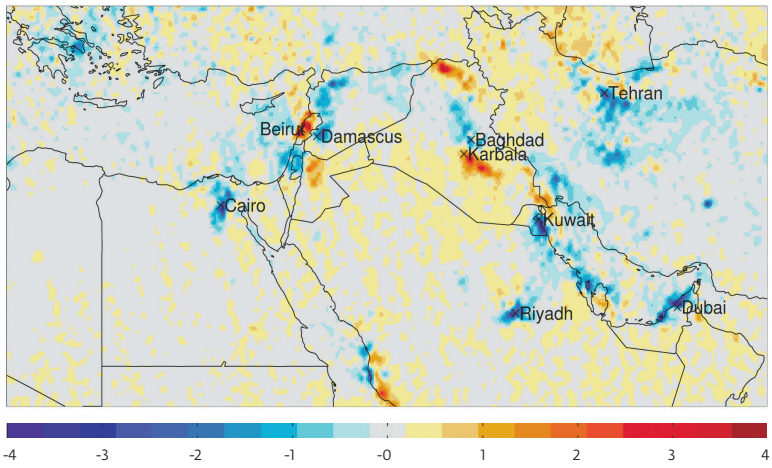
Zoom onto the center: Magnified image of the central 100 light-years around the heart of the Milky Way in the light of the soft X-ray. The galactic black hole and the emission from its surroundings are located in the brightest, central region of the image; the bipolar lobes extend above and below that location.

Photos: LuiKotale Bonobo Project/Zana Clay (top), MPE/ESA (bottom)

Signs of Crisis in the Air

Social tensions impact the quality of the atmosphere

Civil wars, as well as political and economic crises, can have a rapid and dramatic impact on a region's pollutant emissions. That is what researchers at the Max Planck Institute for Chemistry discovered in a study focusing on the Middle East. The scientists analyzed nitrogen oxide pollution in the atmosphere over the last ten years. They determined the data from satellite measurements of atmospheric nitrogen dioxide levels. These indicated that nitrogen oxide emissions fell particularly sharply in regions where armed conflict is taking place – such as Syria – and from where large numbers of people have fled. In contrast, the emissions rose in Lebanon and other regions into which refugees have retreated. "It is tragic that the negative trends we are observing in nitrogen oxide emissions accompany humanitarian catastrophes," says Jos Lelieveld, who headed the study. (Science Advances, August 21, 2015)



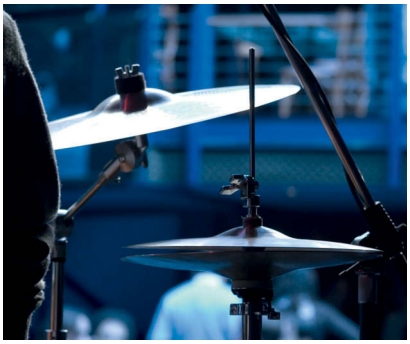
Nitrogen oxide emissions fell in many regions of the Middle East between 2010 and 2014. The colors indicate the changes in the concentration of nitrogen dioxide in 10^{15} molecules per cubic meter of air during the period observed.

Fractals Set the Tone

Self-similar patterns occur in the rhythm and variation of loudness in a drummer's playing

Music may owe its human touch to a mathematical pattern. A team headed by researchers from the Max Planck Institute for Dynamics and Self-Organization in Göttingen and Harvard University in Cambridge, Massachusetts, observed fractal patterns in the playing of Jeff Porcaro, the drummer in the band Toto. This is what mathematicians call self-similar structures, or patterns that resemble one another on a large and small scale. The researchers determined that both the rhythm and loudness of Porcaro's beats vary in a similar way over a whole piece and in just a few bars. People evidently prefer this type of variation: totally precise percussion or beats varied purely at random were perceived as less agreeable. Porcaro is regarded by many fans as setting the standard in drumming. The researchers now want to establish whether fractals also appear in the playing of other musicians. (PLOS ONE, June 3, 2015)

Well-dosed irregularities: Fractal patterns occur in the playing of the drummer of the band Toto.



Baby Blues

The study touches on a taboo: Family happiness doesn't usually occur that quickly after the birth of a child. This is the conclusion reached by Mikko Myrskylä of the Max Planck Institute for Demographic Research and Rachel Margolis of the University of Western Ontario in an analysis of data from a socio-economic panel. On average, mothers and fathers rated their life situation in the first year of parenthood as being 1.4 satisfaction levels lower than in the previous two years. Only just under 30 percent indicated no decline in satisfaction. Over a third of parents revealed a decline of two or more satisfaction levels. Satisfaction falls by only around one level on average as a result of unemployment or the death of a partner. The evaluations also show how experience with the first child influences the chances of a second child being born. Of 100 parents who indicated a drop of two or more satisfaction levels, only around 60 percent had a second child within 10 years. (Demography, August 2015)

Preparing a sample for electron microscopy: The researchers cool a copper grid, measuring just a few millimeters and carrying the protein solution, to nearly minus 200 degrees in liquid ethane within a few microseconds. This prevents the formation of ice crystals in the samples, which would destroy the proteins.

Photo: Frank Vinken

Nano-Sized Lethal Injection

In movies, 3-D effects are spectacular. And also at the **Max Planck Institute of Molecular Physiology** in Dortmund, **Stefan Raunser** finds that three-dimensional images offer a visual feast. His electron microscopes enable him to determine the position of individual atoms with great precision and to study the spatial structure of proteins. In doing so, he occasionally encounters some bizarre constructions.

TEXT **CATARINA PIETSCHMANN**

Nature is full of organisms with unusual life concepts, an impressive example being the tiny nematode *Heterorhabditis bacteriophora*. To reproduce, it crawls through openings in the skin of a beetle larva, where it spits out bacteria that live in its intestine. Bacteria of the species *Photorhabdus luminescens* produce a poison that is lethal for the larva. They then secrete enzymes that break down the dead beetle into its component parts. The bacteria feed on the remains, and the nematodes on the bacteria. Some microbes are not digested, but survive in the worm's intestine and serve as a weapon for the next generation of nematodes.

This is a somewhat unappetizing way of life, but it's useful for the parties involved – a real textbook case of symbiosis. Stefan Raunser finds the bacterial poison and the way it kills the larva fascinating. The poison belongs to the group of Tc toxins, as they are called. Raunser used high-tech electron microscopes to take a very precise look at

this protein complex, which comprises three different proteins, and revealed its structure and mode of operation. Protein A is shaped like a bell with an internal channel. "It has a wide passage and a narrow one, reminiscent of a vuvuzela, the notorious musical instrument favored by South African soccer fans," explains Raunser. Two additional protein molecules, B and C, form a sort of cocoon that envelops the actual poison, a small enzyme at the end of the cocoon protein C. The cocoon binds to protein A at a site intended specifically for this purpose.

As soon as the pH value in the environment decreases or increases, the bell opens up, providing access to the central channel. "The channel is then pushed through the cell membrane like the cannula of an injection needle," says Raunser. A small section of the channel protein produces the energy required for this: it contracts like a metal spring under tension, and the tip of the channel moves forward.

In this process, the cocoon is pulled between the channel and the bell. The cocoon protein C itself cuts off the toxin at its end and injects it through the channel into the beetle cell, with the toxin molecule losing its original structure in the process.

A HIGHLY EFFECTIVE TOXIN

In the cellular fluid, it assumes its regular structure again and changes the arrangement of scaffold proteins, so-called actin filaments. The cell skeleton collapses and the cell dies. "The toxin acts very quickly. The cells collapse within just a few minutes," explains Raunser.

And as if that weren't already crafty enough, the cell even brings in the murder weapon itself. "After the protein complex has docked to the cell membrane, the cell pinches off this piece of membrane inwardly in a small vesicle," explains Raunser. In this bubble-like structure, known as an endosome, the pH value falls, causing the vuvuzela syringe to pierce the membrane of the endosome from inside and inject the toxin into the cellular fluid.

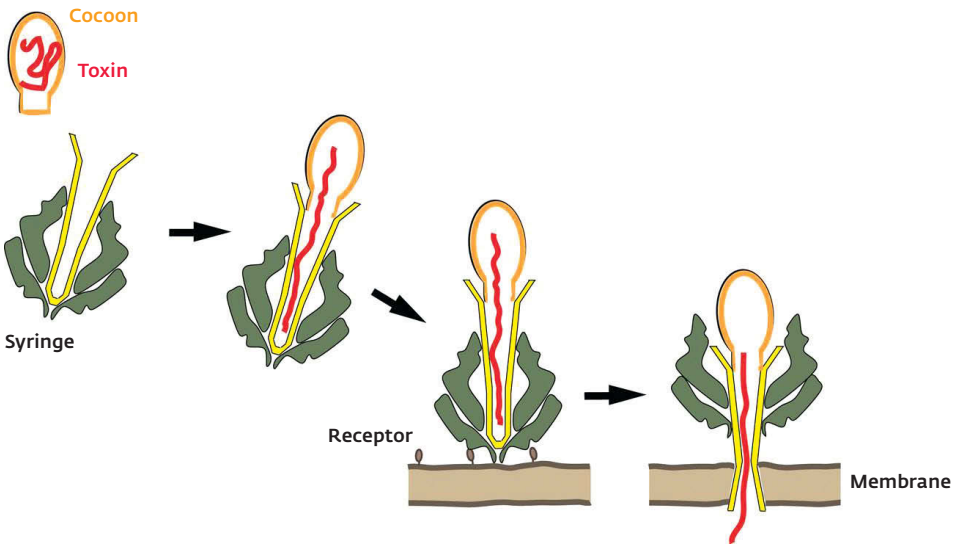
Raunser's team was able to explain the deadly mechanism using cryo-transmission electron microscopy. Unlike with traditional electron microscopy, the sample isn't embedded in a kind of resin, but rather is shock frozen in liquid ethane at minus 196 degrees Celsius. "It occurs so quickly that no ice crystals form that would destroy cells or proteins."

On their path through the sample, the structures of the molecules deflect the microscope's electrons with differing intensities: the greater the atoms' mass, the stronger the interaction. Electron detectors and a computer then produce a two-dimensional image from the captured electrons.

Living cells can't be observed under such conditions, of course. "The vacuum in the microscope would cause biological samples to immediately lose all their water, and the strong electron radiation would quickly damage them," explains Raunser.

For the researchers to be able to reconstruct the spatial structure of the protein complex from the two-dimensional images, they have to take thousands of images from different viewing angles. This means it is advantageous

Photo: Frank Vinken



Left | Yan Nie, Daniel Roderer, Stefan Raunser and Meike Schulte (left to right) analyze the microscope data on the computer. The researchers often don't see the final results of their experiments until months later.

Above | The *Photorhabdus luminescens* Tc toxin, like a classic syringe, is made up of several parts: Two proteins form a cocoon (orange) with the actual toxin (red). A third protein type forms an outer shell (dark green) and a central channel (yellow) that functions as a cannula. If the toxin binds to receptors on the cell membrane and the pH value changes, the cocoon and the channel are pushed forward, and the channel punctures the membrane. Now the toxin is injected into the cell.

when the molecules in the sample are arranged completely randomly: some are lying on their "backs," others on their "stomachs," and yet others are visible from above or below. "What is most important for us are the side views. It's like with photos of people: a person can hardly be identified from the worm's- and the bird's-eye perspective alone," says Raunser. A computer subsequently calculates the three-dimensional structure of the protein using thousands of snapshots.

But it's not just the microscopy itself – the preparation of the samples is also an art of its own. A steady hand and a great deal of skill are needed to load proteins onto a nearly 5-millimeter round copper grid coated with a thin carbon film. Then the whole ensemble must be dipped quickly into the pre-cooled liquid ethane and frozen. "It takes almost a year for new lab members to gain mastery of all the techniques, from preparation to image processing," says Raunser, describing the complex preparation procedure that only a handful of labs in the world master.

Not even a bacterium can survive such a treatment – a beetle larva even less so. Therefore, in order to see how the bacterial toxin develops its lethal effect, the researchers have to employ a trick: they imitate the drop in the pH value that occurs when an endosome is pinched off, and freeze the sample at different points in time. In this way, they can record the various interim states of the toxin and document the individual stages of the intoxication process. The entire cycle can then be played back like a flip-book of individual images.

A TECHNOLOGY CELEBRATES ITS COMEBACK

Thanks to this 3-D cryotechnology, electron microscopy is currently experiencing a renaissance after years of stagnation (see box on p. 50). And just like in its early days, Germany is again one of the leading locations for this technology today. Raunser's microscopes in Dortmund are among the most powerful of their kind worldwide. It's no wonder the 39-year-old from Germany's Palatinate region is serial-publishing the high-profile discoveries made with the methods he refined.

Raunser studied chemistry and biology in Mainz and did his postdoctoral studies at the Max Planck Institute of Biophysics in Frankfurt. He then went to Harvard Medical School in Boston as a postdoctoral researcher before coming to the Max Planck Institute in Dortmund as a Research Group Leader. In 2013, he received more than two million euros from the European Research Council to research this bacterial toxin. Following a brief sojourn at Freie Universität Berlin, he returned to the Max Planck Institute in 2014 and has since headed the Department of Structural Biochemistry.

One of the reasons for the recent triumph of electron microscopy is the incredibly high resolution it allows. "We can almost make individual atoms visible with this technology," says Raunser. In addition, with electron microscopes, it's relatively easy to examine complexes composed of multiple proteins.

High-performance electron microscopes are truly gigantic: the latest gen-

Graphic: Stefan Raunser/MPI of Molecular Physiology

THE HISTORY OF ELECTRON MICROSCOPY

Electron microscopy is a German invention: In 1926, Hans Busch laid the foundation and proved that magnetic coils are similarly good at bundling an electron beam in a vacuum as a lens is at bundling light. In 1932, at the Technische Hochschule Berlin, Ernst Ruska and Bodo von Borries developed an electromagnetic lens. When electricity flows through the coil, a magnetic field is created that can be used to deflect the electron beam. The strength of the magnetic field can be varied by changing the lens current, making the "refractive power" of the lens continuously variable.

From 1937 on, Ruska and von Borries advanced the development of electron microscopes at Siemens & Halske, today's Siemens, in Berlin. Siemens and Zeiss produced the world's first electron microscopes.

This method, which permits 1,000-times higher resolution than light microscopes due to the shorter wavelength of electrons, achieved a scientific breakthrough in the early 1940s. Helmut Ruska, a physician at Berlin's Charité hospital and Ernst Ruska's younger brother, used the technology, also referred to as ultramicroscopy, to visualize such microorganisms as the tobacco mosaic virus, smallpox viruses and bacteriophages for the first time – a real sensation back then.

After the Second World War, Ernst and Helmut Ruska conducted their research in, among other places, the newly founded Max Planck Society. From 1949 to 1974, Ernst Ruska headed the electron microscopy department at the Fritz Haber Institute in Berlin-Dahlem.

In the 1960s, 1970s and 1980s, biologists routinely used the technology to examine cells. Nearly every institute had its own electron microscopy department. These microscopes fundamentally changed our view of life: they made the cell interior visible with previously unparalleled precision.

In 1986, Ernst Ruska was awarded the Nobel Prize – the only one of those involved in the work to receive it, as his brother Helmut and von Borries were already deceased by then.

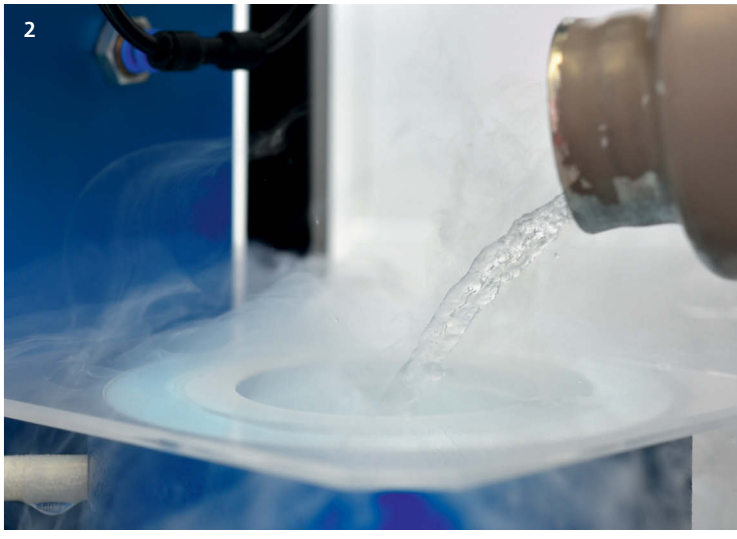
In the 1990s, electron microscopy's importance decreased sharply. New methods entered the competition to revolutionize biology: confocal microscopy and two-photon microscopy. With the help of laser light, science was inching closer and closer to the resolution limit and, unlike with the electron microscope, was now also able to examine living cells. It was now possible to observe many processes live and "in color."

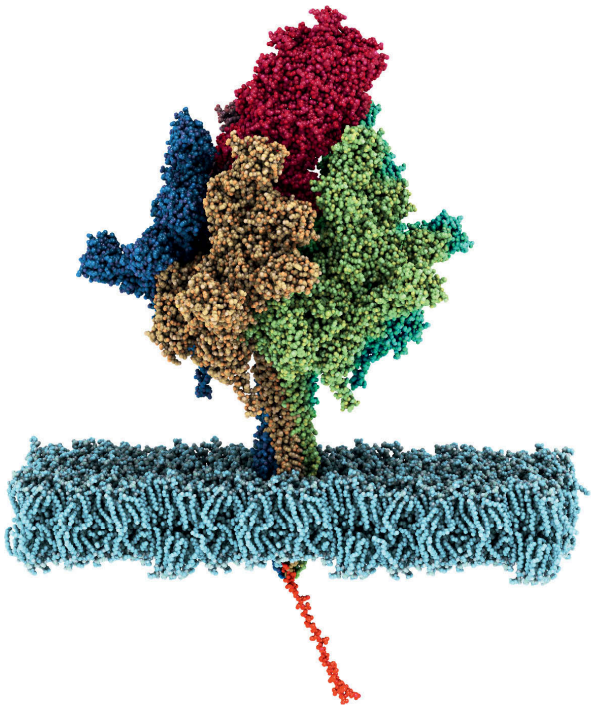
Consequently, many research institutions shut down their electron microscopy departments – only to reopen them shortly after the turn of the millennium: following the sequencing of the human genome, research began to focus on the proteome, the entire set of proteins. Proteins often join together to form larger complexes that then act as molecular machines that perform vital functions, and many of these can only be studied with electron microscopes that afford the required resolution.

Today, Germany is again a global center for electron microscopy. The machines, however, are now manufactured by Japanese and American companies.

For 3-D cryo-electron microscopy, the samples must be shock frozen: Philine Hagel takes liquid nitrogen from a tank (1) and uses it to cool the ethane container (2).

Photos: Frank Vinken (2)





Five molecules of protein A form the injection channel and the outer shell of the toxin complex (four can be seen here). In the interior lies the injection channel through which the toxin (red) is injected into the cell (cell membrane light blue). The cocoon composed of protein B and C is shown in dark red.

eration stands 4 meters high and weighs more than 5 tons. Since they are extremely sensitive to mechanical and electromagnetic vibrations, these instruments have to be housed in specially equipped basements.

ELECTRON MICROSCOPY REQUIRES PATIENCE

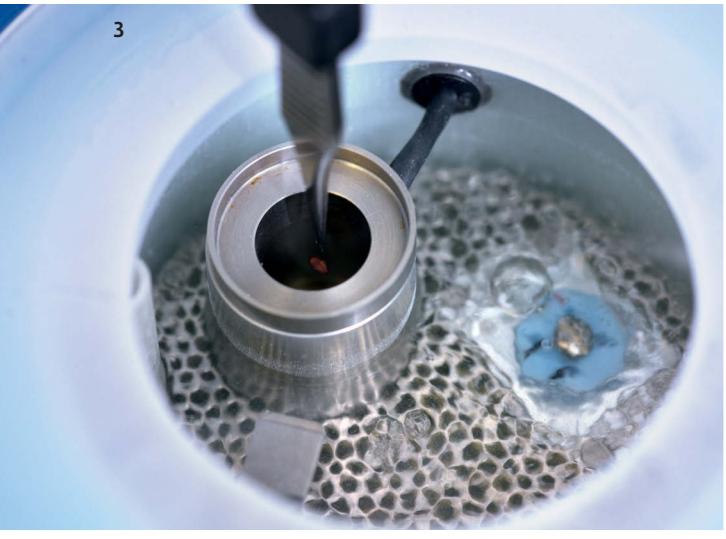
The Max Planck Institute of Molecular Physiology has two electron microscopes for standard tasks. "We use these to look through our samples and choose the best ones." The scientists then examine these using one of the two high-performance cryo-electron microscopes.

The requisite computer capacity alone takes up an entire room. Numerous ventilators are needed to cool the electronic brain as it processes thousands of records simultaneously. It's a long, drawn-out process – a doctoral dissertation in Raunser's group isn't for the impatient at heart. "The microscopy alone takes three months, and the image processing often requires another 18 months. Then it's back to the microscope again," says Raunser.

In clarifying protein structures, the scientist also constantly aims to advance medicine: he hopes his efforts will provide starting points for new drugs. For instance, he is studying the interaction between actin and myosin – proteins that play a role in cardiomyopathies, or diseases of the heart muscle – in muscle cells. Furthermore, he is interested in how the body regulates cholesterol. Three proteins measure whether there is sufficient cholesterol

Photos: Frank Vinken (2), graphic: Stefan Raunser/MPI of Molecular Physiology

The sample is plunged into this container (3) and then put into the electron microscope – here by Oliver Hofnagel (4).



1 | Analyzing the images from the electron microscope requires immense computing power. Alexander Fieroch thus regularly checks the work done by the computer cluster.

2 | Clarifying the mode of operation of these molecular machines in the cell: Stefan Raunser at the Max Planck Institute in Dortmund.

in the body. If not, they ramp up production in the cell. Raunser wants to find out how these proteins cooperate.

EFFECTIVE ATTACK ON BACTERIA

The bacterial toxin produced by *Photorhabdus luminescens* could also be medically important, even though at first glance it doesn't seem to be. Nature also provided microorganisms with toxins that are dangerous to humans, such as *Salmonella* and the pathogen that causes pneumonic and bubonic plague, *Yersinia pestis*.

The findings Raunser's team obtains will help foster a better understanding of how also bacteria such as these operate. Moreover, the Tc toxins could also be used in medicine, as nanoinjectors. This would make it possible to inject drugs into somatic cells – also allowing, for instance, targeted attacks on cancer cells.

"We are currently searching for the toxin receptor on the cell membrane. When we find it and understand how it binds to the cell surface, we aim to alter this region of the protein in such a way that it recognizes cancer cells. This would then make it possible to inject a killer enzyme exclusively into tumor cells," explains Raunser.

He and his team are also trying to insert other active substances into the protein cocoon – using a bacterium's toxin "quiver" as an ultrasensitive drug transporter. But the cocoon could also be used to smuggle in repair enzymes to heal diseased cells.

Incidentally, gardeners – with no awareness of this clever lethal injection – have long taken advantage of the symbiosis between *Photorhabdus luminescens* and nematodes as a natural insecticide. They put a little packet of it into their watering cans, and the toxin of their symbionts unfailingly destroys the insatiable weevil larvae, garden chafers and June bugs that love to feast on the roots of plants. ◂

TO THE POINT

- **The resolution of electron microscopes today is so high that researchers can use them to reveal the spatial structure of proteins. This is ideal particularly for examining proteins that assemble to form large complexes.**
- **Protein complexes work like molecular machines in the cell. Tc toxins from bacteria, for instance, form complicated injection devices with which the microbes can inject a toxic enzyme into cells.**

GLOSSARY

Endosomes: Tiny membrane vesicles that are closed off inwardly by the cell membrane, enabling the cell to transport proteins from its outer shell into the interior. They are part of a transport system comprising a variety of vesicles. On one of these transport pathways, the endosomes fuse with so-called lysosomes, which digest the contents of the vesicles.

X-ray diffraction analysis: A method that can likewise be used to examine the structure of proteins. The X-rays are diffracted by proteins, creating diffraction patterns from which the spatial structure of the proteins can then be calculated. However, this requires that the proteins be in crystal form, which is often technically difficult to achieve. It is very difficult to crystallize large protein complexes.

Photos: Frank Vinken (2)

Captivating shimmer: The Milky Way is part of the system that is home to our Sun and an estimated 200 billion other stars. On a dark night, it shimmers like a nebulous ribbon on the firmament.

Archaeology of the Milky Way

The universe has billions and billions of galaxies, but only one that we can explore star by star in all its dimensions: our Milky Way. It can be thought of as a "model organism" for the formation and evolution of galaxies and is thus a key research topic in cosmology, and the research focus of the team working with **Hans-Walter Rix**, Director at the **Max Planck Institute for Astronomy** in Heidelberg. The researchers recently found indications that quite a number of earlier ideas about our galaxy have to be revised.

TEXT **THOMAS BÜHRKE**

A visitor approaching the entrance to the institute on Königstuhl hill near Heidelberg first notices hexagons chalked on the ground and joined together to form a huge honeycomb. These were left over from the last open house day and symbolize segments of the 39-meter-diameter main mirror that is to collect the light of distant stars and galaxies in the European Extremely Large Telescope in Chile from the next decade on. Astronomers at the institute are involved in developing two cameras for what will become the largest telescope on Earth.

But until it has been built, the explorers of the cosmos must be content with the telescopes that are currently available. This isn't necessarily a disadvantage, as recent years have shown that world-class research can be carried out even with relatively small instruments. The decisive factor here is that the astronomers have been using them to chart the entire sky continuously over many years.

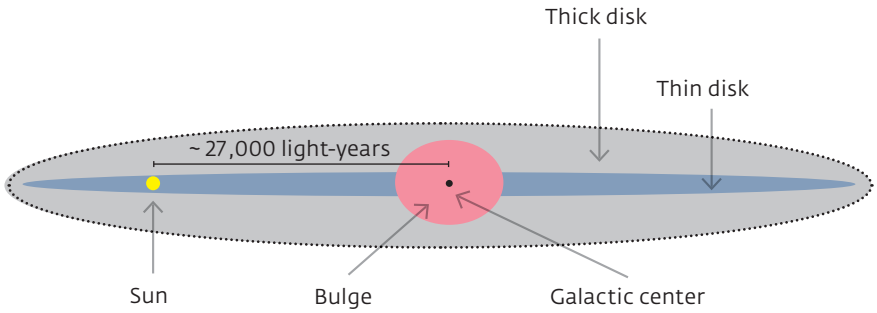
DATA MINING WITH 800 MILLION STARS

This treasure trove of sky survey data contains more information than can currently be analyzed and modeled. "In the very recent past, the quantity and quality of the data has doubled every one to two years," says Hans-Walter Rix. "Ten years ago, we had good spectra from around 8,000 stars; today, it's four million." For a study of the spatial distribution of the dust in the Milky Way, an international team led by Max Planck astronomers has now even analyzed data from almost a billion stars. This, too, has led the researchers to enter the business of big data mining. But what is the point of all this?

"If you want to investigate the evolution of galaxies such as the Milky Way, there are two possibilities," says Rix. "One is to observe galaxies that are increasingly far away from us." Because the speed of light is finite, looking into the distance is always looking into the past. It is indeed now possible to look over a billion years into the past directly at galaxies that formed one billion years after the Big Bang.

Galaxies at different distances from us are therefore at different stages of evolution. However, it is never possible to see one and the same galaxy at different times. Moreover, these galaxies

Photo: Corbis



Two views of the galaxy: The graphic on the left is an edge-on view of our Milky Way system looking from an angle. Two components can be seen in addition to the central bulge: a thin disk of stars close to the center plane and a thick disk that stretches farther into the outer region. Measurements indicate that the thick disk probably doesn't exist at all, but is based on a misinterpretation of data. The illustration on the right depicts a schematic plan view of the galaxy with several spiral arms. Our Sun is around 27,000 light-years away from the center.

are so far away that it is generally possible to make statements only about the system as a whole, since it isn't possible to recognize individual stars.

Rix went down a different path years ago. He investigates the galaxy that is closest to us: our Milky Way. "It is only in our own galactic home that we are able to observe the properties of individual stars in detail, in large numbers and in three dimensions," he says. Fortunately, our Milky Way is a typical galaxy, and what we learn about it can be generalized.

Around half the stars in today's universe are found in galaxies that are similar to our Milky Way in terms of size, mass and chemical composition. "It is something like the Rosetta Stone of galaxy research," says Rix. But how can the evolutionary history of our cosmic homeland be reconstructed if we can see it only in its present state?

The Milky Way is a dynamic system: stars have formed throughout its history. They move on different orbits around the galactic center, bearing some memory of their birth orbit. And they have distinctive chemical compositions, which can serve as chemical fingerprints. The idea now is to determine the properties of as many stars as possible and to deduce their past history with the aid of computer models.

This method is similar to the one used by scientists wanting to understand the migration of a demographic group over many thousands of years by analyzing genetic material. Insiders call it galactic archaeology, and it is now providing completely new insights.

A MASS MONSTER IS HIDING IN THE GALAXY

The Milky Way is a spiral galaxy with a diameter of around 100,000 light-years. It is subdivided into three regions. The very flat disk, just 2,000 light-years thick, is home to around 80 percent of all stars, and has a total mass of about 50 billion solar masses, along with clouds of dust and gas. Our Sun – only 80 light-years away from the center plane – also belongs to this largest population.

Around 15 percent of the stars are found in the central bulge. This is a spherical region around the center with a diameter of around 16,000 light-years. The central body itself is invisible. It is very likely a black hole with a mass of roughly four million solar masses. The remaining 5 percent of the stars move far above or far below the disk in the so-called halo around the central region.

Moreover, the view that the disk has two components – a thin one made up of stars close to the center galaxy, and a thicker one – has become textbook knowledge. The thicker component contains around 10 percent of all stars – including all the old stars – and extends far into the outer regions.

How the thick disk formed, however, remains a mystery. The favored theory assumed that the Milky Way collided with another large galaxy a long time ago, swirling up all the stars that were already in existence at that time

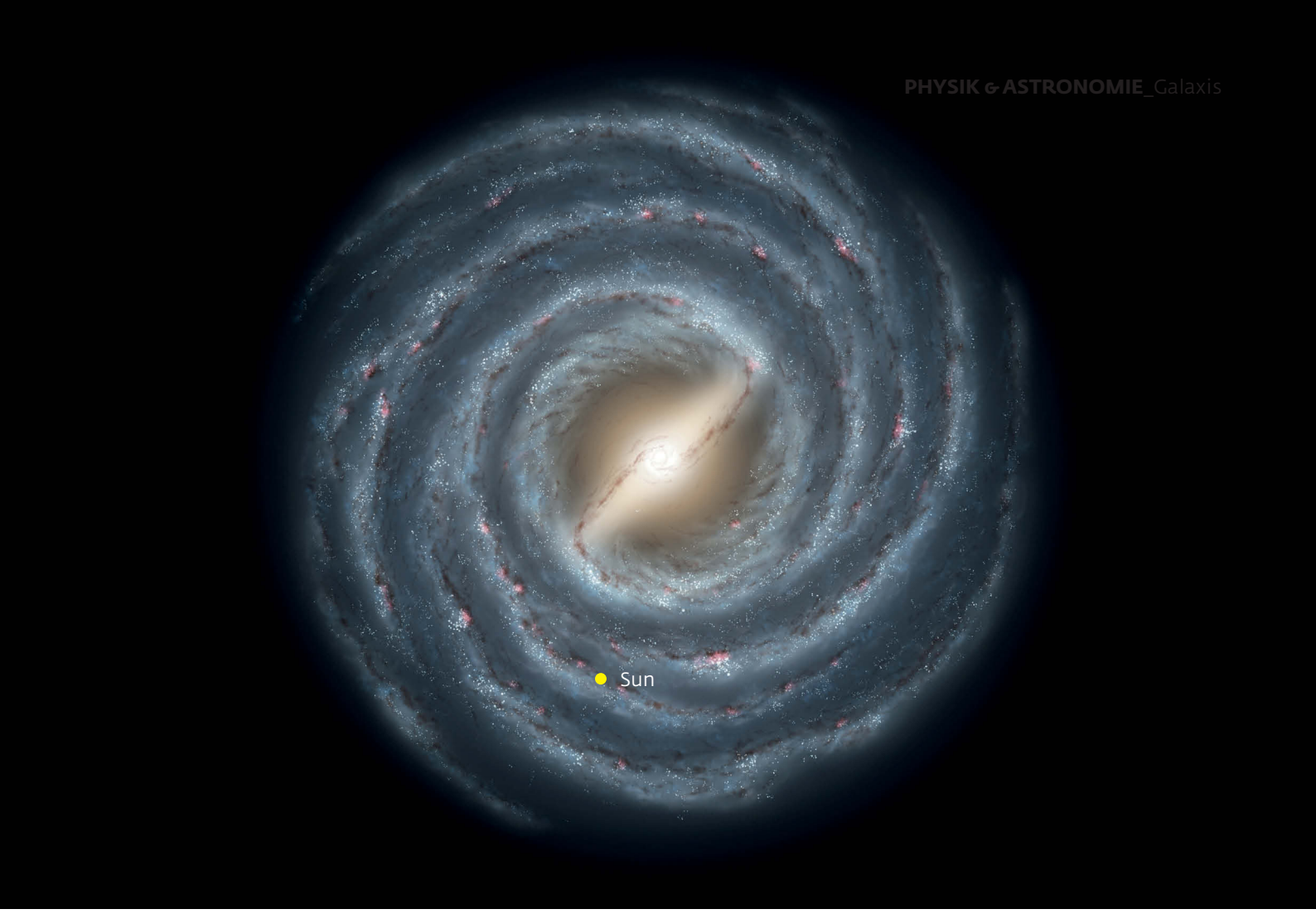


Photo: Robert Hurt/SSC/Caltech/JPL/NASA Robert Hurt

and leading to the formation of the thick disk component.

All stars born after this postulated galactic cataclysm are now in the thin disk. Our Sun is one of them. However, the new measurements now indicate that the existence of such a clearly defined thick disk is probably a misinterpretation based on very limited data material.

Hans-Walter Rix and his colleagues had evaluated spectroscopic data from the Sloan Digital Sky Survey (SDSS). This sky survey is being undertaken with a 2.5-meter telescope at Apache Point Observatory in New Mexico (USA), to which the Max Planck Institute in Heidelberg makes a 25 percent contribution.

The spectra make it possible to determine the chemical composition of around 15,000 stars and group them into populations with the same abundances. The measurable abundances of elements form a lifelong fingerprint on the surface of the star and make it possible to estimate the age of the stars, just like in archaeology.

A crucial result of the SDS survey is that no strict subdivision into the two groups – the thin disk and the thick disk – is evident. The old school of thought that there was a collision with another large galaxy that is supposed to have formed the thick disk will probably have to be discarded. In the meantime, it seems most plausible that, during the turbulent early phase of the galaxy, stars were simply born in a disk that wasn't quite so thin.

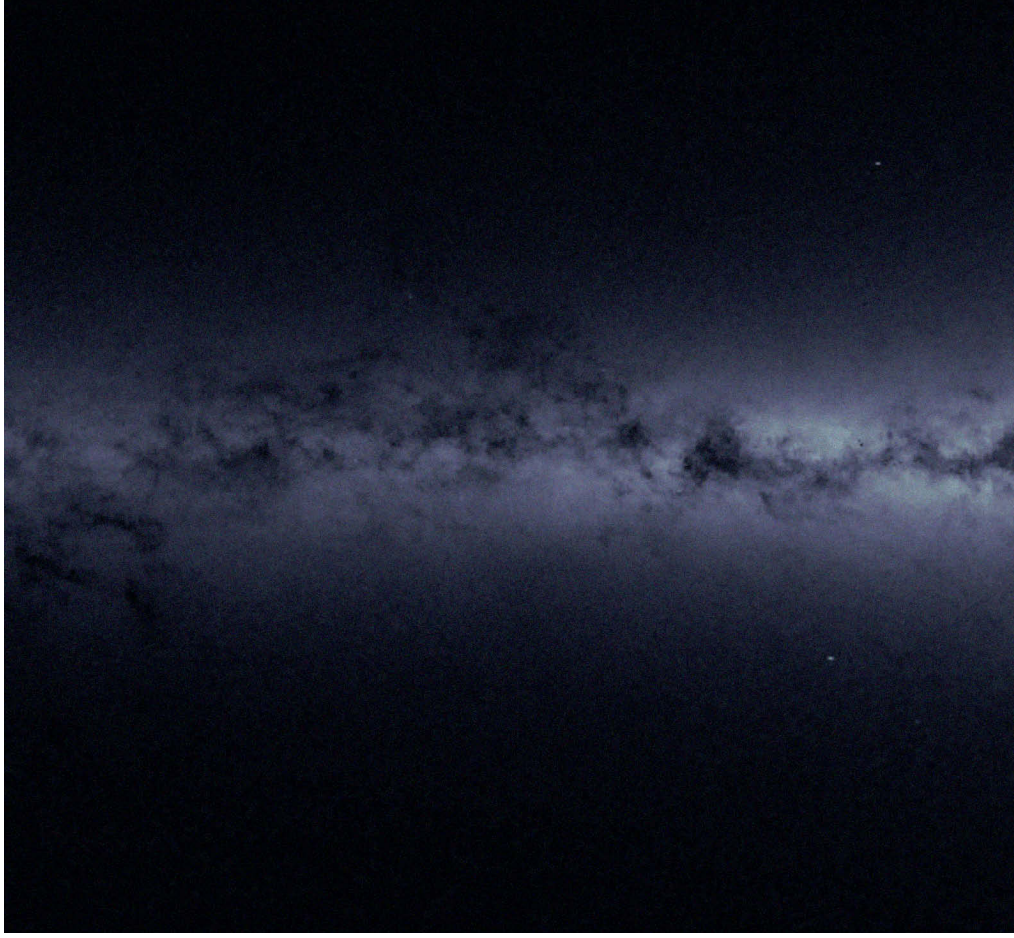
Years later, Rix and his colleagues still occasionally come under fire at conferences for their new findings: many researchers don't like throwing accepted teachings overboard – especially not those that they themselves have developed.

However, the treasure trove of data provided a great many more insights. Maria Bergemann, who completed her doctoral studies at the Ludwig-Maximilians-Universität Munich and recently became the Leader of the Stellar Spectroscopy and Populations Research Group at the Max Planck Institute for Astronomy, plays a crucial role here. Bergemann was able to determine the ages of stars and show that stars become increasingly younger the farther they are from the center of the Milky Way.

MIGRATION IN THE INTERPLAY OF THE SPIRAL ARMS

"This supports a scenario for the formation of the Milky Way that says that the star birth progressed from the inside outwards over the course of many billions of years," explains the young researcher. Galaxies like the Milky Way therefore start from an old center and grow gradually toward the outside – "similar to cities," adds Rix. In this respect, galactic archaeology has already borne many fruits.

However, nature came up with one fact that made it more difficult for the researchers to reconstruct the past: stars that don't have the expected relationship between age and chemical abundance are found in all belts of the



center of the Milky Way. "This finding can be explained by the fact that some stars don't remain on their original orbit around the center, but are able to migrate inwards and outwards," says Rix. New computer simulations support this scenario for the process of star migration.

The Milky Way is a spiral galaxy in which the spirals represent aggregations of gas and stars. If a star comes close to a spiral arm, it is attracted by the stronger gravity and accelerated – like a surfer on a big wave. If that star rides in front of this spiral wave, the star moves farther away from the center of the Milky Way onto a larger orbit. If, after a few hundred million years, this star happens to come under the influence of another spiral arm, but approaches it from behind, it becomes decelerated and moves inwards. Over billions of years, the result is that the star doesn't move on one simple circular orbit around the center, but migrates from one orbit to another – and thus conceals its place of origin.

"We want to try to reconstruct these orbital disturbances by looking for stars that have identical chemical compositions at different locations in the Milky Way," explains Rix. It can then be assumed that they originated in the same dust cloud and subsequently drifted away from each other through influences such as the gravity of spiral arms.

It looks as though the astronomers have to revise not only their ideas about the evolution of the Milky Way, but those about its formation, as well. This requires them to move mentally to the beginning of the universe.

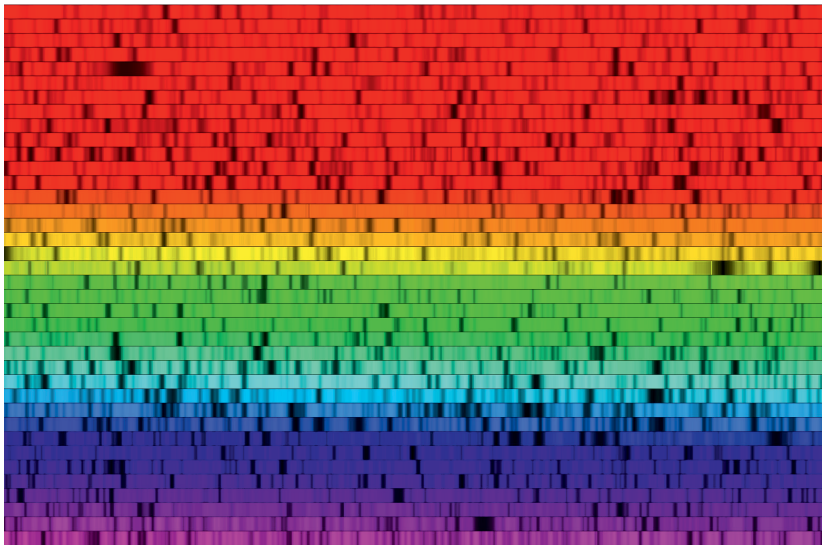
DARK-MATTER PARTICLES EXERT NO ELECTRIC FORCES

After the Big Bang 13.8 billion years ago, the primal gas comprised mainly of hydrogen and helium, on the one hand, and dark matter on the other, formed a relatively uniformly distributed haze. Although researchers still don't know precisely what dark matter is, everything currently points to it being an unknown form of elementary particle that can presently be detected only via gravitational effects. Particularly important is the fact that the particles don't exert any mutually repulsive electric forces. This was crucial at the beginning of the universe because the gravitational force tried to concentrate this matter into large lumps. But the hydrogen and helium nuclei were electrically charged and repelled each other. This prevented the hot gas from being compressed. The dark-matter particles, in contrast, don't exert any electric forces and clustered together to form huge clouds and long filaments.

Their gravitational force attracted normal gas particles. These collected in a well like marbles, and the gas compacted to form the first stars and galaxies. Without the midwifery of the dark matter, there would probably be no galaxies or stars.

According to the conventional school of thought, the large galaxies like our Milky Way didn't form to full size. Rather, there were initially smaller subunits that collided, merged and slowly grew. In this so-called hierarchical formation scenario, large galaxies emerge only in a later phase of the universe.

In recent years, however, astronomers have found more and more large galaxies in the infant universe. "The idea that small galaxies have been the most important building blocks of the large galaxies is a myth," says Rix. Two-thirds of all stars in the Milky Way only formed during the past seven to eight billion years, for example, and thus can't originate from early mergers. The likely scenario is that only around 10 percent of the stars in the Milky Way originate from what



Above: The sky survey: The European space probe Gaia, which was launched in December 2013, is to chart the complete sky in the visible spectrum with very high accuracy. The scout covers more than 100 billion stars in our Milky Way. The photo shows the inventory catalog of the galaxy. The two hazy spots on the right-hand side of the lower part of the image are our two neighboring galaxies, the Large and the Small Magellanic Clouds

Left: Rainbow: The light of a star is broken down into its detailed colors, shown here by lines. Each of the dark stripes represents an absorption line that originates from a specific chemical element. The astronomers use such a spectrum to find out which material the star is composed of and when it was formed.

Graphic: Maria Bergemann/MPI for Astronomy

had previously been small building-block galaxies. The Milky Way probably formed almost "in one piece" in one of these gravitational traps of dark matter.

Computer simulations like those that theoretician Greg Stinson computes at the Max Planck Institute for Astronomy, for example, show that gas from the outer regions initially streams into the gravitational wells of dark matter, where it collects in a turbulent disk. The turbulence from back then still hasn't completely subsided and is reflected in the thick disk, which thus finds a simple explanation.

This doesn't mean, however, that the swallowing up of small galaxies played no role at all in the evolution of the Milky Way. On the contrary: these processes are evident even now.

Just over ten years ago, astronomers in Heidelberg investigated a small globular star cluster 75,000 light-years away called Palomar 5. They discovered that it orbits the Milky Way, passing through its disk again and again as it does so. On its travels, stars were pulled out of the cluster and now reside in two tails around 15,000 light-years in length, which are also known as stellar streams. Computer models predict that Palomar 5 will dive into the Milky Way again in 100 million years and probably dissolve completely.

These stellar streams are extremely difficult to find because, at first glance, their members don't differ from the other stars in the Milky Way. They can

be found only by determining the chemical composition and especially the spatial motion of as many stars as possible. The stripped-off remnants of what used to be the companion galaxy then become recognizable, similar to a shoal of fish in the ocean. They can be detected only in the data of modern sky surveys.

The scientists are currently aware of half a dozen or so stellar streams. The newest members are the Ophiuchus stream, named after the Ophiuchus constellation in which it was discovered, and the Sagittarius stream, the first and biggest stream known, located in the eponymous constellation. The latter forms the tidal debris tail of a dwarf galaxy that orbits the Milky Way on an orbit that is almost perpendicular to the center plane.

The Max Planck astronomers were recently able to record this stellar stream in unprecedented detail with their PanSTARRS sky survey. PanSTARRS has been running on Mount Haleakal in Hawaii for five years. A 1.8-meter telescope equipped with the world's largest digital camera, with 1.4 billion pixels, records three-quarters of the celestial sphere visible from Hawaii every four months.

One feature of such analyses is that they allow the merger and its effects on the Milky Way to be studied in detail. There is, however, a second aspect that makes the stellar streams of interest to cosmologists: their members move on broad trajectories outside the Milky Way through its halo, where they are also subjected to the gravitational force exerted by the dark matter.

With the aid of computer simulations, the distribution of this invisible mass can be computed from the mo-

Top: Cosmic detectives: Maria Bergemann and Hans-Walter Rix from the Max Planck Institute for Astronomy in Heidelberg are trying to get to the bottom of how the galaxies evolved. Our Milky Way serves as their "model organism."

Bottom: Birth in a computer: Theoreticians like Greg Stinson reproduce the birth of entire galaxies in complex simulations. The computations show that gas streams into the gravitational wells of dark matter and collects in a turbulent disk.

Photos: Thomas Hartmann (top), Stinson et al. (2013) "MaGICC" (bottom)

tions of the stars. "If we do this for several stellar streams moving on different trajectories, we can even determine the spatial distribution of the dark matter," says Hans-Walter Rix.

Rix's team is very well integrated into this pioneering research through its participation in the PanSTARRS sky survey. The astronomers additionally hope that the data from the *Gaia* space telescope of the European Space Agency ESA, which was launched at the end of 2013, will take them a giant leap forward. *Gaia* is currently recording the positions, motions, brightness and colors of one billion stars in the Milky Way.

Max Planck astronomers are working on the classification of the stars. In one to two years, they will be able to analyze the first datasets of the mission. "We hope this will lead to the discovery of five to ten new stellar streams," says Rix. And who knows what surprises this treasure trove of data still has in store. ◂

TO THE POINT

- **Our Milky Way serves the astronomers in Hans-Walter Rix's team as a kind of Rosetta Stone that they use to study the evolution of galaxies.**
- **By determining the properties of as many stars as possible and entering them into computer models, the researchers discover the past history of the galaxies.**
- **The textbook teaching that the stars in the galaxy are spread over a thin and a thick disk can no longer be maintained. The theory stating that our Milky Way collided with another large galaxy at some time in the past, leading to the formation of the thick disk we observe, will probably also have to be discarded.**
- **The team headed by Rix has also exposed what some believe – that large galaxies grew gradually by colliding with many small stellar clusters – to be a myth. Two-thirds of all stars in the Milky Way only formed during the past seven to eight billion years, for example, and thus cannot originate from early mergers.**

GLOSSARY

European Extremely Large Telescope: This project of the European Southern Observatory (ESO) is currently being built on Cerro Armazones, a mountain that rises to 3,000 meters in the Chilean Andes. The E-ELT will have a main mirror constructed from 798 hexagonal elements and measuring 39 meters in diameter, and will be the largest telescope on Earth on its planned completion date in 2024.

Sloan Digital Sky Survey: The SDSS is a survey that will cover a quarter of the sky. Its objective is to record the positions and brightness of more than 100 million celestial objects at five wavelengths. It will also acquire spectra from individual objects.

By the time Peter Seeberger arrives at the campus of the Freie Universität Berlin-Dahlem shortly before ten o'clock, he has already accomplished a few things – perhaps the most pleasant ones on his agenda. He has taken his daughter to elementary school, played with his son for an hour, and then driven the three-year-old to the university daycare center. These are things the 49-year-old would like to do more often than just once a week. But his job leaves him little room for maneuver.

Currently, Peter Seeberger also has to commute between two sites: His Biomolecular Systems Department was recently finally able to move into the extension of the Max Planck Institute of Colloids and Interfaces in Potsdam-Golm. Some of his staff, however, are still located in Berlin, at a university-affiliated institute where the 75-member team has been working for the past six years. But Seeberger's Berlin office is already empty, apart from a standard desk-and-chair set, making our conversation echo around the room. Better to retreat to a bench outside to enjoy the pleasant sun of another hot July day.

Peter Seeberger, dressed casually in a polo shirt and jeans, has just launched his fifth company. Vaxxilon, founded by the Max Planck Society and the Swiss-based company Actelion Ltd. in Berlin-Adlershof, will develop and market sugar-based vaccines to prevent bacterial infections.

Sugars, especially those that form long, branched chains and cover cells like a fluffy fur coat, are Seeberger's domain. Attached to proteins and lipid molecules that anchor them to cell membranes, they are a means for cells to interact with their environment – with friend and foe alike. Bacteria and viruses also carry complex sugars on their surfaces and use them to attach to human cells.

Seeberger has developed a synthesizer to automatically produce these sugar chains, which are also known as glycans (see MaxPlanckResearch 3/2013, p. 54). His team is particularly interested in the glycans found on the surfaces of parasites and bacteria that cause tropical diseases like malaria, leishman-

Photo: David Ausserhofer

A Scientist with a **Sweet Tooth**

Basic scientist, entrepreneur, citizen and family man: what **Peter Seeberger**, Director at the **Max Planck Institute of Colloids and Interfaces** in Potsdam, manages to cram into one lifetime would take others three. One of his goals is to prevent diseases that afflict particularly people in developing countries – and his weapon of choice is sugar.

TEXT **CATARINA PIETSCHMANN**

iasis and a particular form of encephalitis. The aim is to develop novel vaccines based on these glycans.

SEEBERGER IS ABLE TO INSTILL ENTHUSIASM IN OTHERS

Sugars alone are not very effective as vaccines. They need an adjuvant, an immunostimulator to enhance its activity. A novel adjuvant has been developed that – unlike conventional carrier proteins – is not a heat-sensitive protein, but a stable glycolipid, a compound consisting of a fatty acid and sugar. Immunization with such a completely synthetic vaccine is less likely to trigger allergic reactions and is also much cheaper, because the substance can be transported to the most remote villages in Africa and Asia unrefrigerated. With conventional vaccines, the refrigeration chain accounts for half the immunization costs.

Vaxxilon, however, will focus primarily on hospital-acquired infections. "We can find investors for these much more easily than for poverty-associated diseases," says Seeberger, who speaks from experience. More on that later.

When the Max Planck Director speaks, his soft Franconian accent is unmistakable. His years spent in the US, Switzerland and even multicultural Berlin have done nothing to temper it. And Peter Seeberger also speaks extremely fast, as though he doesn't want to waste time talking so as to leave enough to implement all the ideas flowing out of his brain.

But these two things are only a brief distraction, because Seeberger has a gift that few possess and that can't be learned: He can quickly put listeners under his spell and instill enthusiasm for his ideas. His candid manner certainly helps him win people over. He speaks plainly and invites his conversation partners to do the same. He is also aware that he sometimes comes across as arrogant – but the longer you listen to him, the more you realize: it's not about himself but about his research.

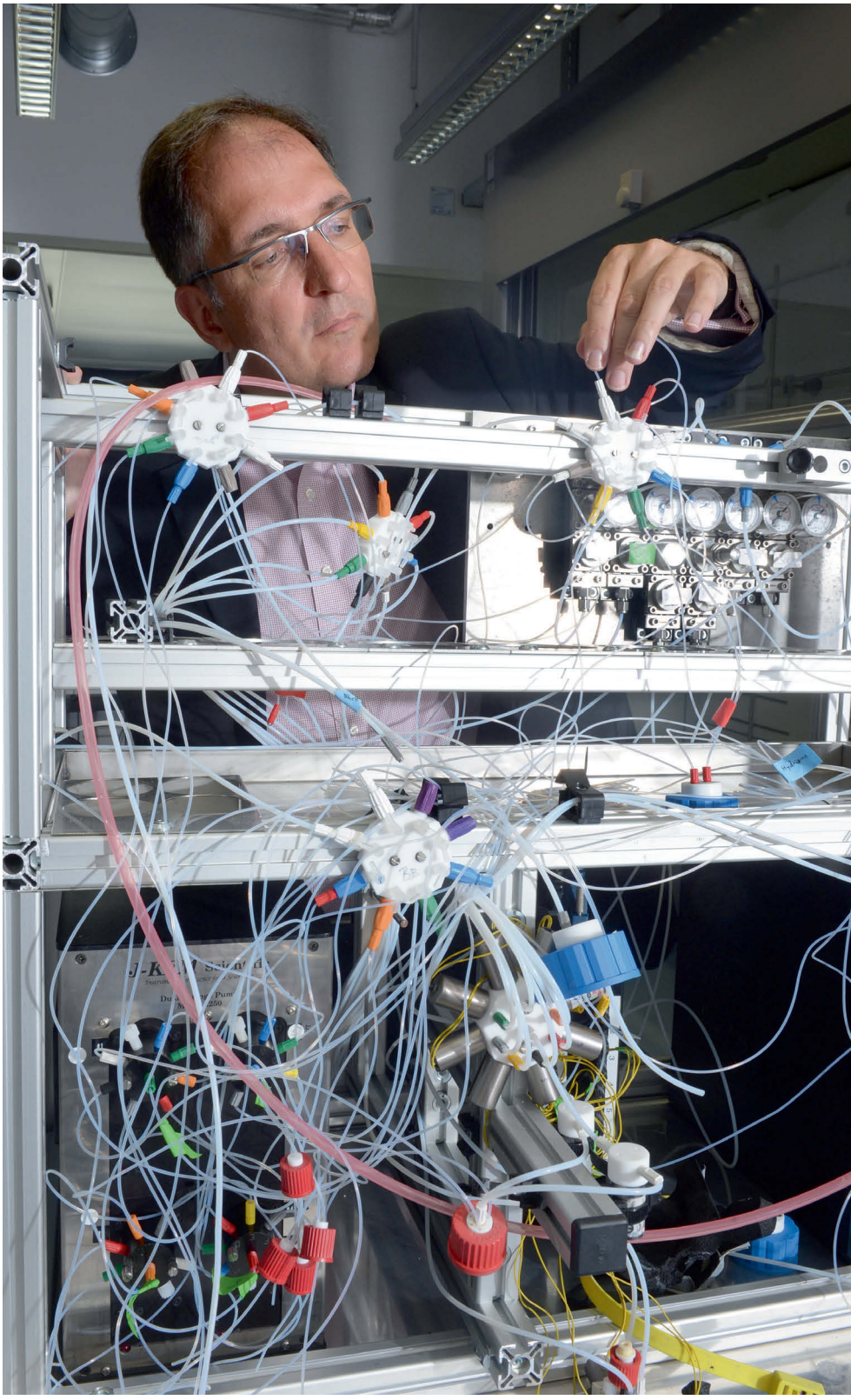
Seeberger was born in Nuremberg and grew up in a caring home. His father was trained as an auto mechanic;

his mother worked in an office. And although he was the first in his family to attend a university, he never shed his no-nonsense roots. As a boy, Peter wanted to become a garbage man, and later, a librarian. Starting in fifth grade, his goal was to become a mathematics professor. Seeberger laughs. "Well, that almost happened." He found learning easy, and his chemistry teacher at his high school in Fürth had no trouble sparking his interest in atoms and molecules. But sports, especially team handball, was often more important than his lessons. The game helped shape his character. "Handball is a team sport, and that is also fundamentally true of a research group."

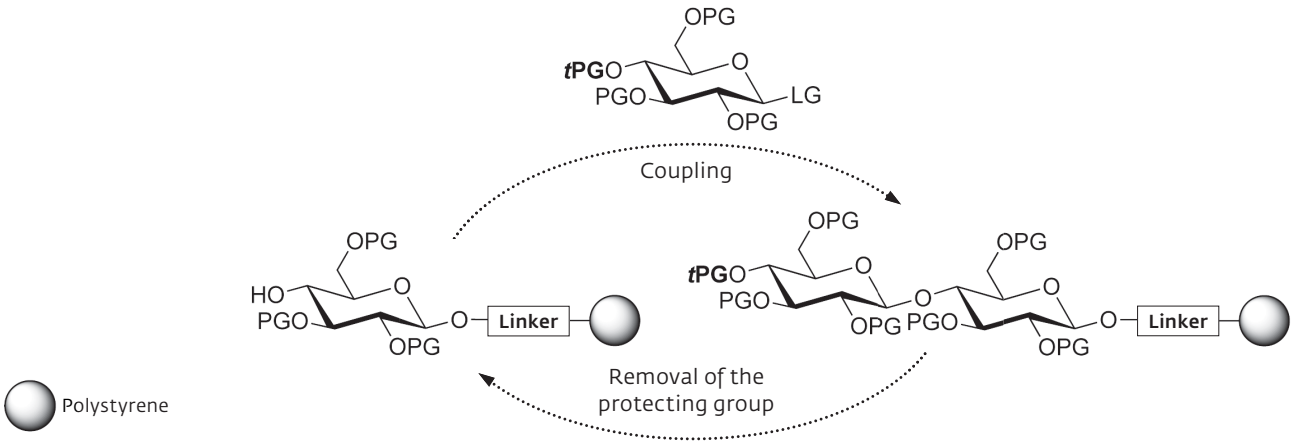
He didn't really apply himself until the final two years of high school, when there was a promise of a scholarship for gifted students. With his high school grades, he could have studied dentistry, but after completing his military service, Peter Seeberger enrolled to study chemistry and economics at Erlangen University. "In an ideal world, I would have become an archeologist, but the job prospects were pretty miserable."

PRODUCING CARBOHYDRATES AUTOMATICALLY?

After six semesters – by which time he had nearly completed all of his degree requirements – he won a Fulbright scholarship on the strength of his grades and, with his BSc diploma in his pocket, traveled to Boulder, Colorado for a year as an exchange student. It soon became apparent that the university was an incubator for outstanding biochemists. But he had studied only chemistry. "I didn't have a clue!" he says. For the first time in his life, he wasn't among the best in his class, but at the bottom, instead. And no wonder – all the classes were in English, which he had pretty much neglected in school, thinking: I'll never need it. After all, I live in Bavaria.



Custom-made sugar: Peter Seeberger developed a synthesizer that facilitates the manufacture of a wide variety of specified carbohydrates.



Building a sugar chain step by step: A sugar molecule is linked to a polystyrene carrier by means of a chemical linker. Protecting groups (PGs) mask most of the hydroxyl groups, thus shielding them from chemical reactions. During the coupling, this molecule combines with another sugar molecule precisely at the site of a leaving group (LG). The attached molecule carries a temporary protecting group (tPG) where another chain link can be attached. As soon as the tPG is removed, the cycle is repeated.

In short: the first year in Boulder was really tough. Seeberger had to hit the books hard. In the breaks between studying, he went to the mountains to ski and hike. When he completed his second semester at the top of his class, he was invited to stay on and study for a doctorate in biochemistry. So he continued in the laboratory of Marvin Caruthers, who had invented the DNA synthesizer in 1980. Although he has a sweet tooth, Seeberger was of course motivated to turn his attention to sugars for entirely different reasons. While he experimented with peptides and nucleic acids for five years, he kept asking himself: if DNA and peptides can be manufactured automatically, why not carbohydrates?

Sugar synthesis was the specialization of Samuel Danishefsky in New York. He accepted Seeberger as a postdoc at the Sloan Kettering Cancer Center, where Seeberger synthesized complex carbohydrates. He worked 16-, sometimes 18-hour days. "But we always had a bit of fun afterwards," he recalls. The team used to go out together, and many a friendship was forged in this period. After all, everyone was in the same situation. And he made time to go to the opera at the Met.

Seeberger actually wanted to teach in Germany, but Danishefsky had other plans for him: Why not take up a post as assistant professor at MIT? When the invitation from the Massachusetts Institute of Technology came, Seeberger moved to Boston. He was only 30 when he became a professor. He built up his research group from its initial 4 members to 35, and published articles in Science about automatic sugar synthesis. He was offered tenure after just three and a half years.

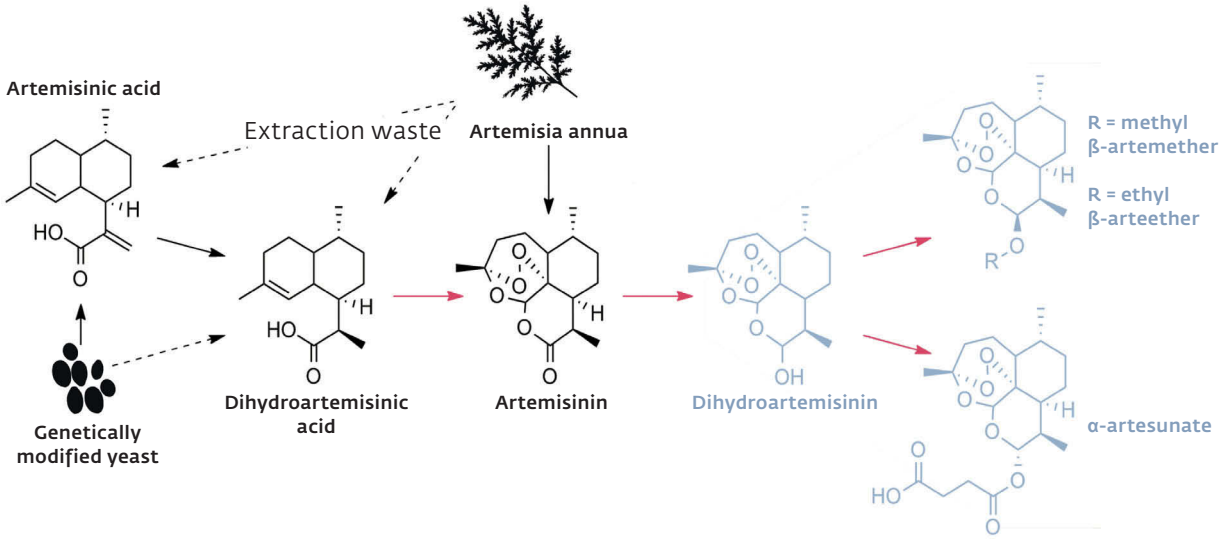
SWITZERLAND – A CULTURE SHOCK AFTER 13 YEARS IN THE US

His work days didn't become any shorter, and his private life was as good as non-existent. Relationships culminated in the reproach: "There's no point. You're never there anyway!" Seeberger, who wanted to have a family at some point, realized with dismay that few of his colleagues at MIT managed to reconcile work with family life. Things seemed easier in Germany, so he was thrilled to receive an offer for an eminent professorship in organic chemistry in Munich. But this soon proved a disappointment. The two sides were unable to agree on terms, and Seeberger turned down the post.

A short time later, the renowned German organic chemist Dieter Seebach from ETH Zurich held a lecture at MIT. After the two discussed chemistry for three hours one Saturday morning, Seebach asked Seeberger to send him his CV. The invitation from ETH came a few months later. "I knew that if I also turned down Zurich after rejecting Munich, I would probably never have been able to return to Europe. The only hope would then be Max Planck." But that seemed to be in an entirely different league. Nevertheless, the interview at ETH went much better than the one in Munich, and Seeberger, now 36, moved to Switzerland in 2003. After 13 years in the US, it was a real culture shock, he says.

He had set up his first start-up in Boston the year before, Ancora Pharmaceuticals, as well as a second laboratory in southern California. Zurich, Boston, San Diego and back – the frequent flyer card was rarely out of use. The work at ETH went exceedingly well. And life in Zurich? A dream! "The only way I'll leave here is feet first," Seeberger thought at the time. But as the old

Photo: David Ausserhofer; graphic: Peter Seeberger/MPI of Colloids and Interfaces



A new approach to a malaria drug: Until recently, artemisinin was obtained only from sweet wormwood (*Artemisia annua*). In the process, however, the artemisinic acid and dihydroartemisinic acid were discarded as waste products. Peter Seeberger's group developed an efficient method to synthesize artemisinin and the currently used active agents (blue) from these substances, which can also be produced in genetically modified yeast.

saying goes: if you want to make God laugh, tell him about your plans …

In 2004, the Society of German Chemists invited Seeberger to Leipzig. For the first time he had to present a lecture in German. "Sure I could still speak German! But I had only ever thought about sugars in English. I didn't know which terms to translate and which not. To be safe, he translated every word, and the audience was very amused. "That was incredibly embarrassing!"

HAVING THE SAME PROFESSION HAS ITS UPS AND DOWNS

But the remarkable thing about this event was something altogether different. Before Seeberger set foot in the auditorium, a few meetings had been arranged with colleagues, including Beate Koksch. They chatted animatedly. She had just received two job offers and asked his opinion: the US or Berlin? "Without thinking, I said: Berlin! It's much better!" Talk about arrogant, thought Koksch.

When Seeberger received the Otto Klung Weberbank Prize a few months later, they met again in Berlin – where Beate Koksch had since moved. "It took a while for us to get together." But the chemistry between them was simply too good – even professionally! So Seeberger added the German capital to his flight plan. When their daughter was born in late 2006, it became clear that their professional situation would have to be adjusted.

A year later the Max Planck Society asked Seeberger to become Director at the Max Planck Institute for Medical Research in Heidelberg. However, for several reasons, Berlin was the better option for him. "The Max Planck Society was extremely accommodating and appointed me to a post at the institute in Potsdam." And because the Max Planck Institute there was already too small and needed a new building, Peter Seeberger pursued research from 2009 on the Freie Universität campus in Dahlem, just a few hundred yards from his wife's research group.

Is it good or bad for a couple to have the same profession? "Both," says Seeberger. "We understand exactly what the other is doing and can always talk shop." That's also a disadvantage. "You have to be careful not to neglect your personal life." When they argue, it's about all the traveling that goes with the job. "Coordinating it is incredibly difficult." Otherwise, everything is well organized. Once the children are in bed, each goes to their respective office and answers e-mails, writes articles or deals with other matters until midnight or even later. Saturdays and Sundays are reserved for the family.

COMPOSITE MATERIALS FROM CELLULOSE AND CHITIN?

Seeberger didn't plan his career; it just happened – thanks to jobs that were usually brought to his attention. "Moving away from a location was always a difficult decision," he says in retrospect. "You never know what lies ahead. But each time I was able to expand my field of research." Whereas Boston was still about sugar chemistry pure and simple, biology and animal experiments for vaccines were added in Zurich. In Berlin he perfected automated synthesis, which another startup, Gly-

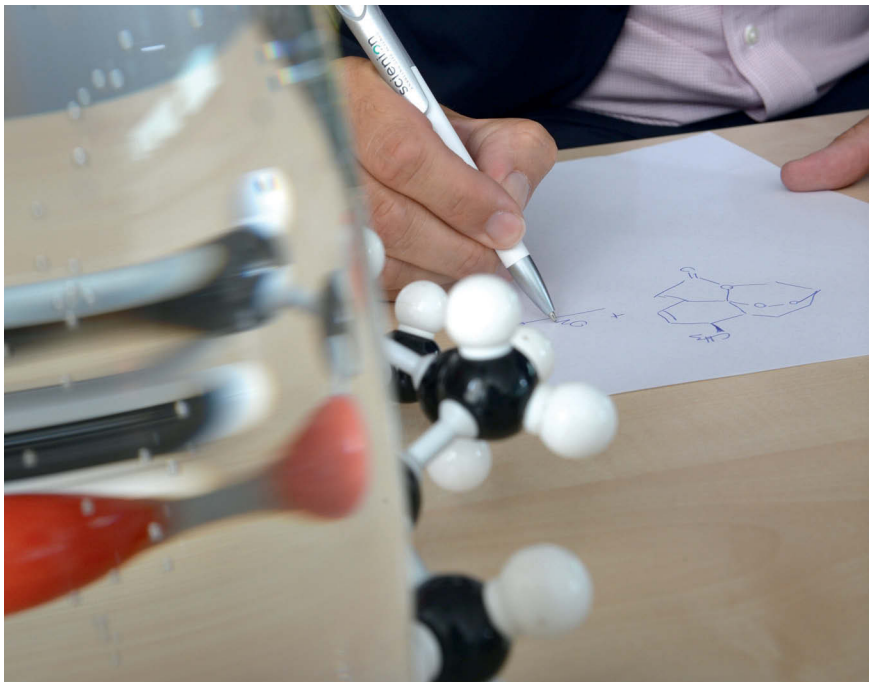
Graphic: Peter Seeberger/MPI of Colloids and Interfaces

coUniverse, has been marketing globally since 2013, complete with sugar building blocks. He also developed flow synthesis methods for some drugs there to simplify their manufacture and make them less expensive.

His colleagues in Potsdam, whose research into biomaterials and interfaces is, at first glance, a far cry from Seeberger's sugars, have given his work fresh impetus. Thanks to the possibility of building chains of up to 50 sugar links, the jump was made from oligosaccharides to polysaccharides – giant molecules that are used in nature as versatile structural materials in the form of cellulose and chitin.

"I had never previously considered structural aspects," Seeberger says enthusiastically. The option of being able to reconstruct these natural materials from scratch raises new questions: Why are carbohydrate molecules branched? What forces are at work? "How do single sugar polymers behave when we throw them on a surface? Do they tangle up? Do they fold? We simply don't know." Chitin and cellulose might be combined to form new composite materials, Seeberger continues. Another research field to be explored. "I see great potential there in the next 20 years." Projects are already under way with his Potsdam-based colleagues Peter Fratzl, Markus Antonietti and Reinhard Lipowsky.

To cover the broad range of Seeberger's research, a group is needed that isn't organized hierarchically but in small complementary teams that can nevertheless work on an interdisciplin-



New office: Many members of Peter Seeberger's group only recently moved into the new building at the Max Planck Institute of Colloids and Interfaces. At his desk, the scientist sketches new reactions on paper – an essential part of chemical research.

Photos: David Ausserhofer

ary basis. “Basically, I hire people who can do something that I can’t.” Besides chemists and biochemists, they include medical doctors, parasitologists, engineers and, most recently, a crystallographer for structural analyses. The team includes 18 nationalities, and that is as it should be, Seeberger emphasizes. “I’m completely intolerant of intolerance. And anyone who doesn’t accept that has to go.”

Does he ever think about what he will do when he retires? Rarely. One thing is certain, however. He doesn’t want to be one of those who can’t stop, who after retirement flies off to conferences or haunts institutes, giving their successors advice. “At some point you have to stop, no matter how hard it may be.”

In any case, he can already look back on an impressive career. His development of synthesis machines, for instance, has made the field of biologically relevant sugars accessible to science. After genomes and proteomes, now also glycomes have become a subject of vigorous basic research. Seeberger’s influence is also evident from what has become of his people: 47 of his more than 200 alumni are professors today, and most of them continue to push the boundaries of sugar chemistry with their ideas. Next year, for his 50th birthday, they will gather from all corners of the world at a symposium in Harnack House.

IT’S ABOUT IMPROVING THE WORLD

Of course Seeberger will continue to follow their work after retiring. But from a distance, because he believes that there should be a life after one’s career. Assuming he is still in good health, he could well imagine being more active in developing countries. For the past 11 years he has been involved in the Swiss Tesfa-Ilg Foundation, which he was instrumental in setting up. The foundation built a plant in Ethiopia in which 300 women now produce insecticide-impregnated mosquito nets.

Where does the urge come from to devote himself – professionally and privately – more to the problems of developing countries than those of industrialized countries? “I’ve always traveled a lot, even as a child with my parents, and I saw very early on that not everyone has it as good as we do.”

He doesn’t see himself as a do-gooder, but his aim is “at the end of the day to make the world a slightly better place.” And he can’t stand it when bureaucratic obstacles and financial interests of corporations make it difficult to produce drugs and vac-

Photo: David Ausserhofer

That's not the whole story by any means: Around 75 people work in Peters Seeberger's group at the Max Planck Institute of Colloids and Interfaces and the Freie Universität Berlin. Less than half of them are gathered here in the new premises in Potsdam.

cines for poverty-associated diseases such as malaria and HIV more quickly and less expensively. Patience isn't his strong suit, he says.

"On the one hand you see people dying of diseases that should no longer exist, because they can't get the drugs, or they get only counterfeit drugs," he says, his anger clearly audible. "For one thing, the drugs could be manufactured cheaply. But in the process of creating value, a lot of people earn a lot of money, and in the end the drugs are so expensive that patients in developing countries are unable to afford them!"

A SUGAR-BASED VACCINE BEFORE RETIREMENT

To remedy this situation, Seeberger has offered pharmaceutical companies his patent for the flow synthesis of artemisinin free of charge – with the proviso that they supply the malaria drug cheaply. The response? None whatsoever.

But thanks to a healthy portion of stubbornness and pragmatism, Seeberger isn't easily discouraged. "I draw energy from resistance," he says grinning. There must be another way! In 2013 he set up ArtemiFlow GmbH, which developed the method to market maturity. And now an alumnus is implementing the artemisinin project with a company in Vietnam. "Malaria is under control in the country itself, but drugs for other developing countries can be inexpensively manufactured there."

Won't artemisinin soon be superfluous, since GlaxoSmithKline plans to apply for approval of the malaria vaccine RTS,S, which the company developed with a 400 million dollar financial injection from the Bill & Melinda Gates Foundation? "In my opinion, that's only a small step in the right direction, because the efficacy of RTS,S in young children is below 10 percent."

From 2001 to 2008 Seeberger teamed up with a company to develop a sugar-based malaria vaccine. In animal experiments it had an initial 75 percent response rate and nearly 100 percent after further development work. But the project was put on ice before the first study with humans. The expected profit was too low, it was said. He was in discussions with the Bill & Melinda Gates Foundation at the time. "But I had to learn that the best technology doesn't always get the money. Contacts and political and commercial aspects are also very important." Because of a secrecy clause, Seeberger was not allowed to talk about the vaccine or even continue to research it for a long time. At least his team is now working on the substance again.

Given his personal ambitions, it's no surprise that he holds the German inventors of the 19th century in high regard. "Because they put their ideas into practice and developed things that improved people's lives. That's what I want to do." Seeberger's research always seems application related, but that was never planned, he emphasizes. It just happened. "I'm interested in basic research. But it's very satisfying if it leads to more than a paper or two." After all, most money for research comes from taxpayers, and they should see that the results are useful.

What does he plan to do in the second half of his career up to the age of 67? "My aim is for us to establish sugars everywhere: in medicine, nutrition and material sciences. There's still a lot to do." Before he retires, he would like to have at least one sugar-based vaccine approved. And it would be nice if his name were one day associated with the term sugar synthesis as firmly as the name Emil Fischer a century before. Seeberger laughs. "Okay, I'm not entirely free of vanity," he says. But you have to set the bar high. "Science is like sports: you should never be satisfied, because more is always possible! And I'm never satisfied." ◀

GLOSSARY

Glycans are carbohydrates that consist of a sometimes branched chain of various simple sugars, such as glucose and fructose. Glycans perform various functions in biology. They not only supply energy but also have a supportive function in plants in the form of cellulose or hemicellulose and enable cells to communicate with their surroundings.

Glycome: The term was inspired by the words genome and proteome. It denotes the entirety of all simple and compound sugars in an organism.

Drilling Deep **into Earth's History**

Life on Earth stagnated for billions of years in the stage of primitive single-celled organisms. Only when cells acquired a nucleus did things really take off, leading to diversification and the dazzling variety of life forms we see today. **Christian Hallmann** and his team at the **Max Planck Institute for Biogeochemistry** in Jena are investigating how, when and where that happened.

TEXT **DIRK LIESEMER**

Christian Hallmann, a geologist from Bremen, had to travel thousands of miles in a cross-country vehicle before finally reaching the Pilbara Craton, a particularly ancient piece of Earth's crust in the northwest of Australia. Only a few shrubs are able to survive in this parched area. On the rust-red plain, he and a small international team are drilling hundreds of meters into the 2.7-billion-year-old rock – delving down into a unique archive of Earth's history to obtain information in the form of rock samples. The scientists then examine the samples in search of minute traces of early life forms.

For months, Christian Hallmann and his colleagues from the US and Australia prepared the drilling that would be performed with machines as tall as houses. They are the cleanest drill holes of their kind ever sunk. Meticulous precautions were taken to recover the rock samples. The aim was to settle a controversy in historical geology. Among other things, the researchers wanted to clarify when eukaryotes arose in the oceans. Eukaryotes are life forms that pack their genetic material in a cell nucleus. Originally consisting only of single cells, over the course of Earth's history the eukaryotes gave rise to all complex multicellular organisms, including plants and animals. The first appearance of nucleated cells therefore marks a key point in evolutionary history.

LIPIDS AS MOLECULAR FINGERPRINTS

Until now, there have been conflicting theories in this regard. The first known microfossils of eukaryotes are approximately 1.5 billion years old. Yet in 1999, several researchers reported discovering 2.7-billion-year-old traces of eukaryotes in rock samples from the Pilbara Craton. They believed that they had found steroid hydrocarbons, or more specifically the remnants of eukaryotic lipids, which probably served in early eukaryotes to stabilize cell membranes and create separate compartments such as the cell nucleus. Thanks to this compartmentalization of cells, biochemical processes could run more efficiently, especially in large cells, which was a prerequisite for the development of more complex life forms. Today, these particular lipids serve as molecular fingerprints of eukaryotes. Critics, however, soon warned that the detected hydrocarbon abundances were much too low to provide reliable results. In addition, they claimed, over the course of Earth's history, the rocks experienced exceedingly high temperatures, which would have destroyed these telltale molecules.

Were the putative traces of eukaryotes in fact impurities? Christian Hallmann set out to answer that question. "We had to work as cleanly as possible in Australia," says the geologist. As early as the planning stage, he and his colleagues considered how to protect the rock samples from contamination, especially with hydrocarbons from the lubricants used in the drilling equipment. Lubricants are used to prevent damage to the machines, speed up the drilling process and reduce noise, but their petroleum-derived residues could contaminate samples and easily be confused with original eukaryote traces. Roger Buick from the University of

Photo: MPI for Biogeochemistry

Meters and meters of Earth's history: Christian Hallmann and his colleagues store the bulk of core samples from the Pilbara Craton in aluminum crates.

» How did the Earth develop so that complex life forms were able to spread at the end of the Precambrian?

Photo: MPI for Biogeochemistry

To drill cleanly into the Earth's crust, the researchers used water to which they had added fluorescent microparticles and isotopically labeled hydrocarbons. In this way, they were able to tell how deeply contaminants penetrated into the rock.

Washington in Seattle, who organized the drilling for the study, therefore spent weeks looking for a company that would drill without such lubricants. That's what research problems can boil down to – especially when dealing with such intangible matters as early life forms.

That's precisely what Christian Hallmann deals with. At MARUM, the Center for Marine Environmental Sciences at the University of Bremen, he leads the Organic Paleobiogeochemistry Research Group, which is affiliated primarily with the Max Planck Institute for Biogeochemistry in Jena. Hallmann focuses on the Precambrian, the eon that spans more than 85 percent of Earth's earliest history. It began four and a half billion years ago, while the Earth was forming, and ended 541 million years ago, immediately before the explosive diversification of complex multicellular life forms.

The four billion years of the Precambrian were characterized by enormous changes. Nutrient cycles developed, while the chemical makeup of the oceans and atmosphere fluctuated wildly and the climate repeatedly swung from one extreme to another. The planet was probably covered in ice several times, making it seem like a giant snowball.

The factors that led to extreme glaciation are one of the questions that occupy Christian Hallmann and his American and Australian colleagues. They also want to know how the Earth

Office in the outback: Christian Hallmann (left) and his cooperation partners spent nearly one and a half months in the Pilbara region. The researchers washed the core samples obtained from the ground with organically clean water (right). They looked for 2.7-billion-year-old biomarkers of eukaryotes in only a small proportion of the samples, which were immediately sealed. The majority, as seen here, were sent to colleagues around the world for various analyses.

developed during the Precambrian, leading to the burgeoning of complex life forms at the end of the eon. How did the Earth develop from an inhospitable environment with no oxygen in the atmosphere and vast quantities of iron in the oceans to the planet it is today? "I want to know, for example, when, why and under what environmental conditions the first eukaryotes arose," says Hallmann. "And how these life forms ultimately brought about today's Earth system – complete with oxygenated air and modern nutrient cycles."

For a long time during the Precambrian, only simple single-celled organisms lived, such as bacteria and, later, eukaryotes. The Precambrian is therefore still regarded as a time of evolutionary stagnation. Only during the final era of the Precambrian, known as the Neoproterozoic, did more complex multicellular organisms, plants and the metazoa (from the Greek for multicellular animals) evolve. The latter include all the animals we know today, and they all originated from the first simple forms. At the beginning of the Cambrian, 541 million years ago, all the precursors of today's animal phyla developed almost simultaneously within an astonishingly brief geological period of a few million years.

Christian Hallmann is particularly interested in the ecological conditions that facilitated the Cambrian species explosion. After all, eukaryotes, including plants and metazoa, require oxygen to produce energy. For a long time, only the precursors of cyanobacteria in the oceans produced this elixir of higher life. "From an environmental perspective, eukaryotes could, theoretically, have emerged 2.45 billion years ago, because sediments deposited at that time show evidence of the first oxygen in the atmosphere," says Hallmann.

BIOMARKERS SURVIVE FOR BILLIONS OF YEARS

To gain new insights into the evolution of eukaryotes, metazoa and their environments, Christian Hallmann is collecting rock samples from various sites formed during different epochs of Earth's history. His Australian samples come from the very early phase of our planet; some samples from Brazil and Siberia come from the time before the Cambrian species explosion. Analyzing rocks from various regions around the world is important for developing a sense of whether environmental changes were global or regional.

In the samples from the Pilbara Craton in Australia, Christian Hallmann and his colleagues are searching for the hydrocarbon remnants of biological lipids – especially steroids. Unlike other biological molecules that can also be very typical for specific life forms, these hydrocarbon biomarkers can theoretically survive in sediments for billions of years. In contrast, the genome, probably the most reliable molecular fingerprint of organisms, degrades rapidly and vanishes without a trace. "It's only in science fiction films that researchers find DNA originating from the primordial Earth," says Hallmann.

But even steroids and other lipid remnants can survive the passing eons only under ideal conditions. Above all, as little oxygen as possible should be present in the water during deposition of the sediments – like a park pond that has lost its oxygen because of too much duck feed. Clay minerals and some limestones can preserve the structure of the molecules, even as the molecules themselves are structurally converted within those minerals. Porous sandstone, by contrast, is completely unsuitable for the preservation process. Arne Leider, a colleague of Christian Hallmann, is investigating how the original molecules are transformed within various rock types. Only if these underlying processes are properly understood will researchers be able to interpret the molecular traces in their samples correctly – that is, if they find any.

For the search to be successful, it is not enough for the biomarkers to be enclosed in suitable rock. There are very few places on our planet that have re-

Photos: MPI for Biogeochemistry (2)

Searching for traces in the laboratory. Arne Leider (left) and Christian Hallmann interpret chromatographic analyses in order to identify biomarkers of eukaryotes and their breakdown products.

mained unchanged since the Precambrian. No oceanic sedimentary rocks exist at all from the first billion years of Earth's history. They are weathered, or the organic material they once contained has been converted into graphite that no longer contains any biological information. Or the rock has been recycled back into the interior of the Earth by tectonic activity and has melted. Even rocks from later epochs have frequently been overprinted by elevated temperatures as a consequence of tectonic movements, to the extent that any organic molecules they may have contained have been cracked or destroyed. To determine whether information on the original substance can nevertheless be gleaned for altered molecules and their fragments, Arne Leider is also investigating what happens to relevant biomarkers under the effects of heat.

The oldest known traces of petrified life occur in 3.5-billion-year-old rocks from Australia. These onion-like structures, known as stromatolites, were formed by bacteria that grew layer upon layer. Today, actively growing stromatolites can be found in only a few places that offer the right conditions, such as in a bay in Western Australia where larger grazing animals are absent due to elevated salinity.

CORE SAMPLES WERE OFTEN LEFT EXPOSED FOR YEARS

Geologists know of only two regions containing two- to three-billion-year-old rocks that might still harbor molecular traces of primordial eukaryotes: the Pilbara Craton in Australia and the Kaapvaal Craton in South Africa. Only at these two sites have the rocks not been excessively heated over the course of time. If eukaryotes already existed 2.7 billion years ago, their traces should be found here, the scientists reasoned.

In the summer of 2012, Hallmann and his colleagues prepared the boreholes in Australia. The work was largely funded by the Agouron Institute in Pasadena, in the US. His coworkers were from MIT, the University of California, Riverside, Macquarie University in Sydney, and the Australian National University in Canberra.

Geochemists still find it extremely difficult to obtain rock samples from the Precambrian that are free of impurities and to correctly analyze them. Accordingly, few groups have succeeded in doing so. In the past, many researchers have used core samples extracted from the ground by mining and petroleum prospecting companies. Not only do these companies typically use huge quantities of synthetic lubricants, but some core samples had been stored openly exposed to the air for years, allowing dust or diesel fumes to settle on them. Only then were they collected by or passed on to scientists.

Even at the Pilbara Craton site, it was uncertain whether the drilling would be successful. No one knew, for example, whether the freezers would maintain a constant temperature of minus 20 degrees in the heat of the outback in order to prevent volatile substances from escaping from the samples. And, of course, the purity of

Photo: Tom Pingel

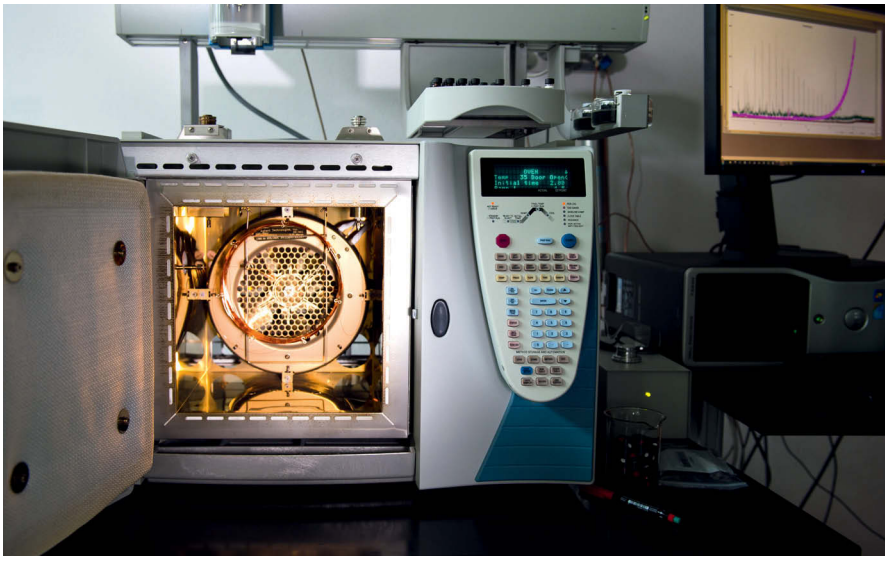
the samples was crucial. The researchers first cleaned the core barrels with synthetic detergents. They then drilled several hundred meters down into volcanic rock that contained no organic matter. In the process, any residual impurities on the drill rod were rubbed off by abrasion. The only lubricant allowed was groundwater.

Originally the researchers wanted to bring enough organically clean water for the drilling operation with them from their base in Perth. But that proved impossible: the distance was simply too great. Instead, the team searched on site for days for an underground source of water. They then sank a well and pumped groundwater above ground, where they stored it in a tank to allow any particles to settle to the bottom. Organically clean water was brought to the field site only in sufficient quantities to wash the samples.

They then added a fluorescent substance to the water, to dye it a luminescent green, as well as synthetically labeled hydrocarbons. These would later tell them how deeply water – and therefore potential impurities – had penetrated into the rock samples. Similar fluorescent beads had previously only been used in studies of the present-day 'deep biosphere' to determine how deeply bacteria of the same size as the beads can penetrate into core samples. The search for early eukaryotes in the outback marks the first time that organic geochemistry researchers have exercised such meticulous care in obtaining core samples.

They soon realized just how difficult, loud and slow drilling without lubricant can be – particularly since the drilling rods had to penetrate extremely hard rock strata. Only after 100 meters was the rock devoid of signs of oxidation and weathering, which affects minerals and destroys organic material. Below that level, the rock has essentially remained unchanged for billions of years.

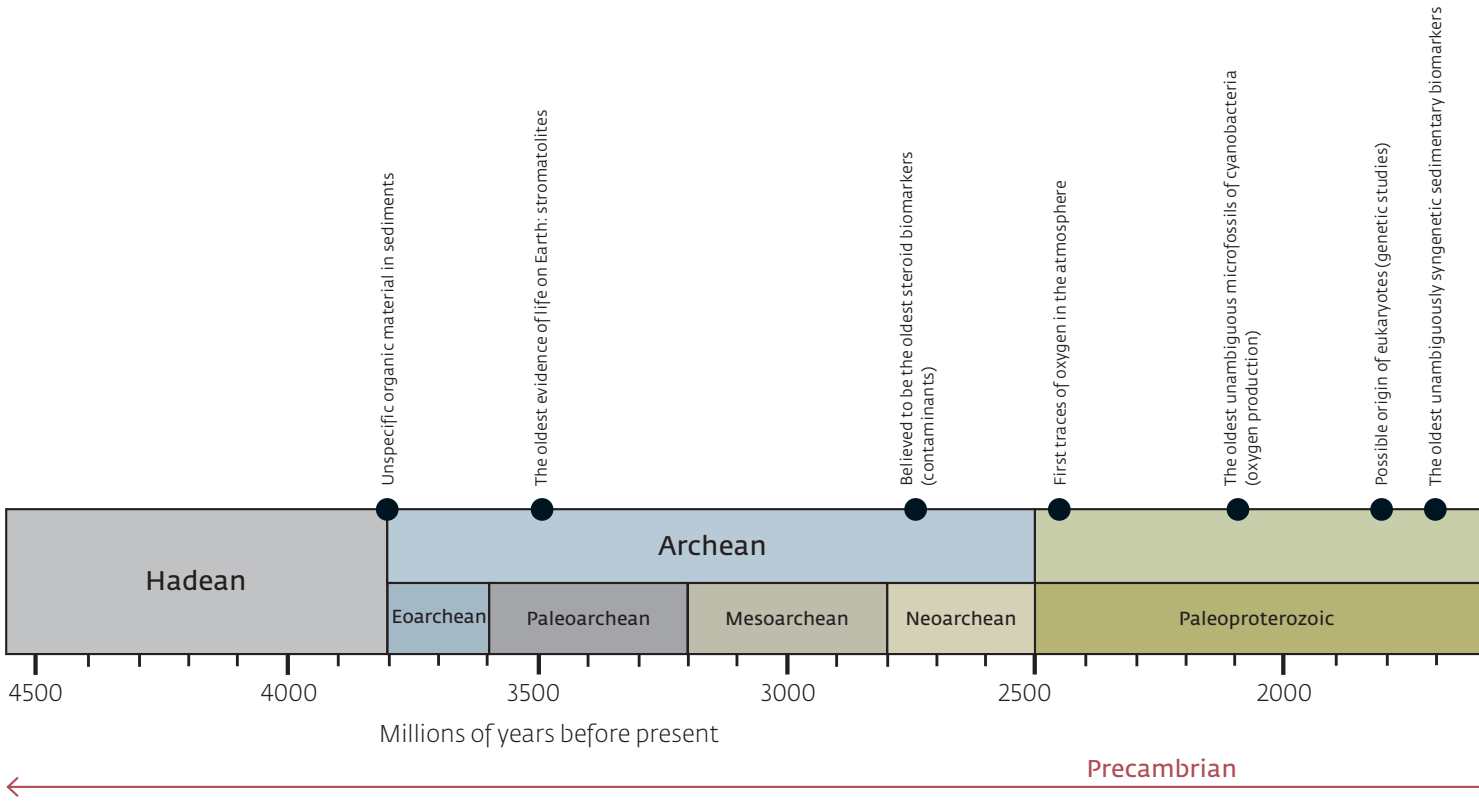
Gradually, the samples were brought up to the surface. The researchers opened up the five-meter-long core barrels and carefully transferred their treasure to aluminum boxes. They then rinsed the core samples with organically clean water and carefully broke it up into sections with a hammer. Then they used clean aluminum foil to lift out the pieces that appeared interesting for their



Above: A rock core of black shale is sawn into portions to allow the researchers to determine whether impurities have penetrated beyond the outer layers.

Below: A view into the open oven of a gas chromatograph shows the rolled-up capillary tube, in which a mixture of substances, such as lipids, is separated.

Photos: Tom Pingel (2)



study and placed them in Teflon bags that had previously been boiled in acid to remove any organic contaminants. After that, they filled the bags with the inert gas argon so that the samples would not be exposed to the oxidizing effects of the air. Quickly sealed, the bags were placed in a freezer, where they remained at minus 20 degrees.

The scientists had originally reckoned that the expedition should take no longer than three weeks to complete. In the end, they had to spend nearly one and a half months in the desert. Hallmann sees the fact that the drilling was a success as a milestone. The samples were safely transported to Perth, although the drive with the heavy freezer on the bed of a pickup truck proved pretty bumpy. During the three-day trip, they had to stop every few hours to cool down the freezer with their own generator, and then from the power supply at camping sites.

The samples were later transported on dry ice from Perth to Canberra by a courier. In Jochen Brocks' laboratory at the Australian National University, the researchers split up their treasure with a clean saw and conducted the first analyses. Katherine French took some of the samples to MIT, while Christian Hallmann took others to Bremen. Hallmann's coworkers used a gas chromatograph and a tandem mass spectrometer to analyze the samples. The former separated out the thousands of organic compounds, while the latter structurally identified the molecules that emerged from the gas chromatograph at various times.

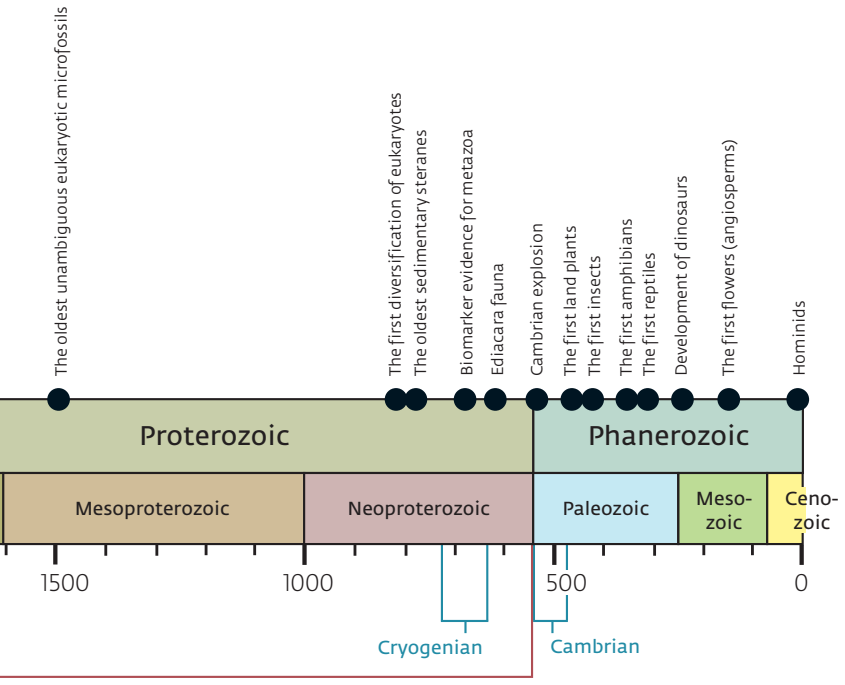
NO TRACES OF EUKARYOTES IN THE PILBARA CRATON

The research teams from the US and Germany analyzed the samples independently of each other, but the results were the same: the ancient rock from the Pilbara Craton contained no biomarkers for eukaryotes 2.7 billion years ago. This was concluded in the summer of 2015. "We now know that the entire region was so hot at least once in the course of its history that we can no longer detect any steroids, even if they were once present," says Christian Hallmann. However, that is unlikely. "We know with relative certainty that eukaryotes have existed for the past 1.5 billion years," Christian Hallmann says. This finding is based on microfossils and is consistent with genetic "molecular clock" analyses. The first single-celled eukaryotes probably arose in coastal water into which rivers carried nutrients.

Moreover, eukaryotes probably played an ecologically relevant role for the first time only around 750 million years ago. At that point, eukaryotic algae experienced a strong diversification and spread across the planet. Today, many eukaryotic algae produce certain volatile chemicals that can attract water droplets around them when they enter the atmosphere. The abundance of such cloud condensation nuclei, as they are called, could have drastically increased at this point in time. More clouds formed, allowing less sunlight to reach the cooling Earth. When the supercontinent Rodinia broke apart, vast quantities of freshly generated rock underwent rapid weathering and drew so much carbon dioxide from the atmosphere that the Earth cooled dramatically and disappeared under a mantle of ice and snow. This period is appropriately known as the Cryogenian.

"For a while I've had this idea that eukaryotes might have contributed to the Earth becoming a snowball," says Hallmann. He recently presented such a scenario together with Georg Feulner and Hendrik Kienert of the Potsdam Institute for Climate Impact Research.

Graphic: Christian Hallmann/MPI for Biogeochemistry



Evolutionary puzzle: Paleontologists and paleobiogeochemists are working to piece together when various life forms arose. They divide the various eons of Earth's history into periods, such as the Cryogenian and the Cambrian. Christian Hallmann is particularly interested in the conditions under which eukaryotes arose, and the explosion of species in the Cambrian.

The two scientists simulated the role of eukaryotes in the Earth's early climate. They found that the spread of eukaryotic life forms could indeed have contributed to a cooling of the climate and ushered in the subsequent ice age.

These findings are underscored by the fact that the supposed traces of 2.7-billion-year-old eukaryotes turned out to be contaminants. The lipids found in 1999 were so complex that they looked like the signature of a modern algal community. This would have suggested that eukaryotes had already differentiated and disseminated widely by 2.7 billion years ago. Cumulative findings of sedimentary steroids and especially microfossils, however, are starting to indicate that this didn't happen until 800 to 750 million years ago. "That's highly consistent with the extreme cooling that occurred around 700 million years ago," says Hallmann.

Thus, with the help of paleobiogeochemistry, the researcher has discovered something about the change in the primeval conditions for life. He continues to delve deep into Earth's history to uncover further information about this tumultuous phase of life that stands at the root of our very own existence. ◂

TO THE POINT

- **The appearance of eukaryotes paved the way for more complex multicellular life forms to evolve – including, eventually, ourselves. When, where and under what conditions this occurred is still not entirely clear.**
- **An international team headed by researchers from the Max Planck Institute for Biogeochemistry has developed an extremely clean method for collecting and correctly analyzing rock samples that are billions of years old, in order to shed light on the origin of eukaryotes and the change in environmental conditions on Earth.**
- **According to the preliminary results, eukaryotes didn't originate 2.7 billion years ago, as has long been suggested, but probably only around 1.5 billion years ago.**
- **The rapid diversification and spread of eukaryotic algae may have contributed to the occurrence of at least one extreme ice age on Earth around 700 million years ago.**

GLOSSARY

Eukaryotes: Organisms whose cell contains a nucleus, and today, also organelles. The organization of cells into subunits allowed cellular processes to run more efficiently. As a result, single-celled organisms could evolve into more complex multicellular life forms.

Gas chromatography: In this chemical separation method, mixtures of gaseous substances are separated as they move through a long, thin capillary tube. The inside of the capillary tube is coated with a material to which the various substances have different affinities. Different substances therefore flow through the capillary tube at different rates, depending on their polarity and volatility, and separate into a number of fractions.

Craton: Ancient continental rock that has mostly been altered by pressure and heat in the course of Earth's history.

Metazoa: This group comprises all complex and multicellular animals.

Tandem mass spectrometry: An analytical method that links two mass spectrometers (MS) into one. In the first MS, substances are ionized with low energies and then selectively separated according to their mass-to-charge ratios. They are subsequently fragmented, and individual fragments are further separated in the second MS. The fragments can then be used to identify the original substances present with high sensitivity and selectivity.

Returning to Berlin as a Living Mummy

One hundred years ago, **Albert Einstein** completed his general theory of relativity – a revolutionary description of gravitation as an inherent property of space and time. During this landmark phase of his life, Albert Einstein was supposed to take over as Director of the newly founded **Kaiser Wilhelm Institute for Physics** in Berlin. However, the plan was delayed by the outbreak of World War I.

TEXT **THOMAS BÜHRKE**

On November 25, 1915, Albert Einstein held his seminal lecture before the Prussian Academy of Sciences in Berlin. It ended with the words: "Thus, the general theory of relativity as a logical edifice has finally been completed." This was followed by days and weeks full of exuberant enthusiasm. Einstein remarked to friends that the theory is "of incomparable beauty," and that his wildest dreams had been fulfilled. He confided in physicist Arnold Sommerfeld that it was "the most momentous discovery I've made in my life."

His audience, however, didn't share this view. Even Max Planck and Max von Laue, who had always supported Einstein, remained skeptical. "A free, unprejudiced view is not at all a characteristic of (adult) Germans," Einstein had written to his friend Michele Besso several years before. Was a new theory of gravitation really needed, given that Newtonian physics had served so well for a quarter of a millennium and appeared to explain everything?

Isaac Newton described gravity as action at a distance: two bodies, like the Earth and moon, are joined as if by invisible threads. But the mechanism by which the force is transmitted was unclear. In addition, Newton's formulas conveyed the impression that gravity reaches another body instantaneously – with no time lag – no matter how distant. This was contradicted by Einstein's special theory of relativity from 1905, according to which no physical effect can propagate faster than the speed of light.

Two giants of science: Fritz Haber (left) and Albert Einstein in Berlin in 1914. Haber had advocated a physics institute within the Kaiser Wilhelm Society early on. It was finally set up in 1917 – with Einstein serving as its Director.

Einstein's description of gravity, known as physical gravitation, is entirely different. He concluded that gravity is a property of space and time: matter bends space around it, and space forces matter to describe specific motions. The moon orbits the Earth not because invisible lines of force connect the two bodies, but because the Earth and the moon distort the fabric of space like steel balls on a rubber sheet, and they move around each other within the resulting distortions.

Gravity is a property of space and time or, more precisely, space-time geometry. In this respect, it is unique. All other forces of nature act within space and time. Gravitation is space and time. Max von Laue, who was initially unconvinced, later wrote that curved space "is by no means a mathematical construct, but a reality that is inherent in all physical processes. This discovery is Albert Einstein's greatest achievement."

Almost as astonishing as the result itself was the process of discovery. Einstein developed his theory of gravitation almost single-handedly. Only once did he need the help of his friend Marcel Grossmann, when he was unable to find his way through the mathematical thicket. Luckily, Grossmann surmised what Einstein needed: the mathematics of curved space, which Bernhard Riemann had developed in the mid-19th century.

In the mid-1990s, together with colleagues from the US, Jürgen Renn and Tilman Sauer of the Max Planck Institute for the History of Science in Berlin traced Einstein's convoluted process

Photo: Archive on the History of the Max Planck Society, Berlin

Director in the attic: Albert Einstein headed the Kaiser Wilhelm Institute for Physics from 1917 to 1922. His daily trip to work wasn't a long one – the institute was housed in Einstein's apartment in Schöneberg.

of trial and error. Their work was based on notes that Einstein had kept in Zurich between the summer of 1912 and the spring of 1913. The notes showed that Einstein had already found the correct field equations toward the end of 1912 – but erroneously discarded them. He did so because of his stipulation that the new theory must contain Newton's formulas as a limit for very weak gravitation. In determining this limit, Einstein made a simple mathematical error that he didn't discover until 1915.

As early as July 1913, Max Planck and Walther Nernst asked Einstein, who at the time was a professor for theoretical physics at ETH Zurich, whether he would be interested in taking up a post at the Prussian Academy of Sciences. He was also slated to become the Director of the Kaiser Wilhelm Society, which was being set up at the time. Einstein agreed, as he was attracted by the prospect of a research post without teaching obligations. Another major factor in his decision was the possibility of living near his cousin Elsa, whom he had fallen in love with during an earlier visit to Berlin.

Berliner Illustrirte Zeitung, December 14, 1919

» A new giant in world history: Albert Einstein, whose research has completely revolutionized our view of nature and is on a par with the discoveries of Copernicus, Kepler and Newton.«

His colleagues hoped that Einstein would give fresh impetus to the quantum theory, which promised great opportunities for scientific and technical progress. Einstein, however, let it be known that he wasn't at all sure whether he would be able to "lay a golden egg" in this field. Above all, he didn't want to focus on quantum physics at all, and his colleagues soon realized this. As mathematician David Hilbert once noted with resignation, "Einstein is evidently so engrossed in gravitation that he's deaf to everything else."

The Kaiser Wilhelm Society had been founded just a short time before, in June 1911. The aim of its institutes was to pursue research exclusively, for which they were generously funded by such donors as entrepreneurs and financiers, among others. The first facilities included the Institute for Physical Chemistry and Electrochemistry and the Institute for Chemistry, both in Dahlem. The time was now ripe to set up a physics institute as well.

Luminaries like Fritz Haber, Walther Nernst and Max Planck advocated such an institute, and on March 21, 1914, the Senate of the Kaiser Wilhelm Society resolved to found one. Their decision was greatly facilitated by a promise from banker and industrialist Leopold Koppel to provide the building and assume one-third of the costs. Another third would be provided by the Prussian government.

But not long afterwards, the plans were scrapped: On July 31, 1914, the Ministry of Finance rejected any further funding. The next day, World War I broke out, and the project was put on hold. Albert Einstein nevertheless travelled to Berlin: "At Easter I'm traveling to Berlin as an academic individual without any obligation, as a living mummy, so to speak. I'm looking forward to this trying profession!" he wrote to his friend and colleague Jakob Laub.

A stroke of luck then occurred that led to the foundation of the Kaiser Wilhelm Institute for Physics on October 1, 1917, when Berlin-based industrialist Franz Stock offered a donation of 540,000 marks. However, Einstein didn't move into a grand building, but resided in his flat at Haberlandstrasse 5 in Schöneberg, where he lived next door to his cousin Elsa.

The organization of this institute differed considerably from that of any other Kaiser Wilhelm Institute. It was managed by two boards: a six-strong Board of Trustees and a Board of Directors, of which Einstein was a member. However, Einstein tried to reduce meetings to a minimum. During his term of office from 1917 to 1922, the Board of Directors met only eleven times.

Unlike other institutes, the annual budget was to be used mainly to fund research projects at external institutes in as many areas of physics as possible. It was hoped that Einstein would give fresh impetus to the solution of theoretical questions, but he was unhappy with this arrangement. Einstein had little financial freedom, and the Board of Directors wasn't willing to support projects to test general relativity.

Overall, around three-quarters of the projects funded by the Kaiser Wilhelm Institute for Physics in the period from 1918 to 1922 dealt with the refinement of quantum theory in some form. "It's clear that the KWI for Physics made important contributions to advances in physics," concludes Giuseppe Castagnetti of the Max Planck Institute for the History of Science, who chronicled the history of the KWI for Physics several years ago.

Ultimately, Albert Einstein wasn't the right person to head such an institute. He had no interest in launching new projects and bringing together scientists to carry them out. He therefore stepped down as Director of the Institute in 1922, and the post passed on to Max von Laue. Just a few months later, the former "Institute Director without an institute building" was awarded the Nobel Prize for Physics.

Photo: S. Tamaru/Archive on the History of the Max Planck Society, Berlin

"Young Researchers Demand Open Access"

Interview with Ralf Schimmer and Ulrich Pöschl on new developments

The worldwide publication system for scientific literature can be converted to Open Access without the need for additional funding. It is sufficient to redirect the funds that are now paid to the publishers for subscriptions. This is the heart of the white paper currently being discussed internationally by experts. In December they will meet in Berlin for a conference. The following interview was conducted with the principal author Ralf Schimmer and Open Access pioneer Ulrich Pöschl, Director at the Max Planck Institute for Chemistry.

Mr. Schimmer, around 13 percent of all specialist articles are published by Open Access. The vast majority continue to be issued via the subscription model – in other words, the articles are bought by way of subscription. Is it not too early to question this business model?

Ralf Schimmer: On the contrary – it is exactly the right moment. The growth rates in Open Access are constant. The share increases every year by about one percentage point, which means that the change would happen by itself anyway. Recently, however, we have had to recognize that skeptics were increasingly speculating that Open Access could well increase the cost of global publishing. We had to confront this fairytale. Consequently, we have presented an analysis that is novel in its clarity and empirical robustness, including with respect to financing. The article is being discussed around the globe, a number of scientific committees have it on the agenda, and publishers are also concerning themselves with it. A total of some 16,000 downloads confirm the desired impact.

Mr. Pöschl, was it a surprise for you, that – as the study shows – a conversion of existing journals to Open Access is possible with the available funding and that money would even be freed up for new investments?

Ulrich Pöschl: The study confirms that the principle of the conservation of mass and energy applies to the publication industry and to Open Access. All relevant journals are already online, and a conversion to free access does not incur any costs whatsoever. If the big commercial publishing houses achieve high margins of up to 40 percent, there must be room for savings. This has already been proven for many years by successful Open Access publishers. What I found surprising and pleasing in the study was that the changeover, also within and between different institutions and countries, will function well.

You are the rapporteur for Open Access in the circle of Max Planck Directors. How strong is the support?

Pöschl: Our discussions among the Scientific Members of the MPG show a very positive attitude overall, especially in the natural sciences with their large international journal market. In the humanities there are some reservations due to different forms of publications, which we naturally take into consideration. For more than ten years the MPG has been working for the conversion to free access to scientific knowledge, and this continues to be one of our research policy targets.

As a joint founder of the journal Atmospheric Chemistry and Physics you have experience with Open Access. What has to happen to dispel the worries about quality deficits?

Pöschl: The classical peer review is 100 percent compatible with Open Access. There are many OA journals that operate very successfully with it and enjoy a high reputation, such as PLOS Biology or eLife, a journal that the MPG itself helps to support. Open Access also offers the reviewers better access to relevant sources and – over and beyond this – many chances of making peer review better and more efficient with interactive elements and transparency. In the geological sciences we have been practicing a transparent review process for nearly 15 years with a total now of 15 specialist journals. And all these titles rank among the top journals in their fields – also in comparison with long-established subscription journals.

Mr. Schimmer, you write that the transformation leads to new publication services that correspond with the digital standards of the 21st century. What does that mean?

Schimmer: Besides the core services – i.e. data processing and publishing – it covers such topics as marketing. Here, experiments are currently running as with eLife: in this case, the abstracts are converted into video messages from the author, which is very interesting for propagation in social networks. Services like this will be professionalized separately by suppliers that will additionally enter the market.

Pöschl: Here we can see that classical publishers that currently rely on the subscription model acquire such start-ups, as in the pharmaceutical industry, or develop products themselves. This also applies to the area of evaluation, as evidenced by Google, for example.

But Google is not an example of the classical publication world …

Pöschl: Correct. When it was still a company in a garage, Google could develop the best search algorithm because it had free access to general Internet contents. This free access has not been available so far for scientific publications, where an unbearable oligopoly structure prevails for indexing and statistical citation analysis. It was only in re-

Illustration: ingimage/creaface

cent years that Google was able to use its market strength to penetrate this closed society and offer, with Google Scholar, an alternative service for compiling publications and citations for every scientist. When Open Access is implemented, there will be enormous progress in the statistical evaluation of specialist articles as we have seen on the general Internet in recent decades, because everyone will be able to develop improved algorithms. One can imagine more meaningful citation rankings, due to qualitative weighting. Semantic methods will determine the context in which an article or author has been cited. That is just one example of how quality assurance and evaluation benefit. Who can best provide these services will be shown in free competition.

That amounts to the meta level of Open Access. Back to publishing: what changes will occur here in the role of publishers and libraries?
Schimmer: As mentioned, classical publishers are also reacting to the signs of the times. In our initiative we don't see them as something that has to be overcome. Quite the opposite, they are invited to participate in the journey. And the libraries have great opportunities for improving their profile in the conditions of Internet-based scientific work. Here the classical libraries just have to develop their concepts and operational processes further. They will no longer receive the journals by subscription, but will arrange the publication of each individual paper in an Open Access journal. Here they remain basically what has always characterized them: the organizers of the business relationships of their institutions with the publishers.

How articles are paid for

Scientific publishing must satisfy high requirements, including quality assurance. This, as well as the professional processing, costs money, but unlike in the classical subscription model, where the reader pays via the subscription, in Open Access the costs of publication will be charged only once (Article Processing Charge, APC). The study assesses how high these publication costs are on average in Open Access. For Germany, this sum is currently around 1,250 euros per article. The conclusion is that if research organizations and libraries use their available subscription budgets to pay the APC, Open Access will be globally possible without additional funds.

The article appeared in spring – where does it go from here?
Schimmer: The next step must now be to discuss these great challenges in research policy and the way forward with the leading international scientific organizations at the Open Access conference in Berlin in December. On the basis of our analyses we would like to sound out the extent to which the goal of overcoming the subscription model is shared internationally. What is decisive is that many supporters state with one voice: we will now invest the money that previously flowed into subscription in Open Access models. The mechanism of this changeover is simple, as shown in the white paper.
Pöschl: Time is on our side here. In day-to-day research and at conferences I can feel that young researchers in particular increasingly demand and promote Open Access. They want to link their work to their researcher profiles in social networks, and it is no longer acceptable to them to live with the Closed Access of the traditional subscription journals in the otherwise so open world of the Internet.

Interview: Jens Eschert

The study can be downloaded at:
http://openaccess.mpg.de

Nobel Laureate Speaks at Harnack House

There are many sides to Alvin Roth's personality: He came to economics through his research into game theory – with such success that in 2012 he was awarded the Nobel Prize for Economics. He is a proven theoretician, but with a mission to solve real problems. Max Planck President Martin Stratmann in his introduction at Harnack House stressed that: "Alvin Roth is a truly exceptional researcher and ranks among the most prominent economists of our time. It is an honor to welcome him here among us."

Roth, who researches and teaches at Stanford in his capacity as Professor of Economics, explained the principle of market design: Using game theory as a basis, algorithms have been developed that govern the fair distribution of certain commodities. Roth cited kidney donations as a vivid, as well as impressive, example of how this works. Under normal circumstances it is rare for patients to receive kidneys from live donors, given that the organs of willing relatives are often medically unsuitable. So with many individuals having the same problem, but being unaware of the existence of others, Roth developed an exchange system that brings them together. Suitable organs are placed by means of "cross donation". This swap system, which is based on a complex algorithm, is functioning successfully in the US, and the number of transplants is rising.

In Germany, on the other hand, this model is not permissible, since individuals are prohibited from donating organs to strangers. Roth also made it clear in his lecture that any form of market design requires social consensus. The number of questions from the audience regarding ethical aspects illustrates the need for discussion on the subject of organ swapping.

Alvin Roth seen here during his Harnack Lecture in the packed Goethe Saal. This annual event is held in memory of the Founding President of the Kaiser Wilhelm Society, Adolf von Harnack.

Photo: Amac Garbe/MPG

cent years that Google was able to use its market strength to penetrate this closed society and offer, with Google Scholar, an alternative service for compiling publications and citations for every scientist. When Open Access is implemented, there will be enormous progress in the statistical evaluation of specialist articles as we have seen on the general Internet in recent decades, because everyone will be able to develop improved algorithms. One can imagine more meaningful citation rankings, due to qualitative weighting. Semantic methods will determine the context in which an article or author has been cited. That is just one example of how quality assurance and evaluation benefit. Who can best provide these services will be shown in free competition.

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Photo: Amac Garbe/MPG

Alvin Roth seen here during his Harnack Lecture in the packed Goethe Saal. This annual event is held in memory of the Founding President of the Kaiser Wilhelm Society, Adolf von Harnack.

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Translation
Baker & Harrison Translations
Ferdinand-Maria-Straße 30, 80639 Munich
Tel. +49 89 8583608-0
e-mail: cb@bakerharrison.de

Art Direction
Julia Kessler, Sandra Ostertag
Voßstraße 9, 81543 Munich
Tel. +49 89 27818770
e-mail: projekte@designergold.de

Lithography
KSA Media GmbH
Zeuggasse 7, 86150 Augsburg

Printing & Distribution
Vogel Druck- & Medienservice GmbH
Leibnizstraße 5, 97204 Höchberg

Advertising
Beatrice Rieck
Vogel Druck und Medienservice GmbH
Leibnizstraße 5, 97204 Höchberg
Tel.: +49 931 4600-2721 (Fax: -2145)
e-mail: beatrice.rieck@vogel-druck.de

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