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Max Planck RESEARCH

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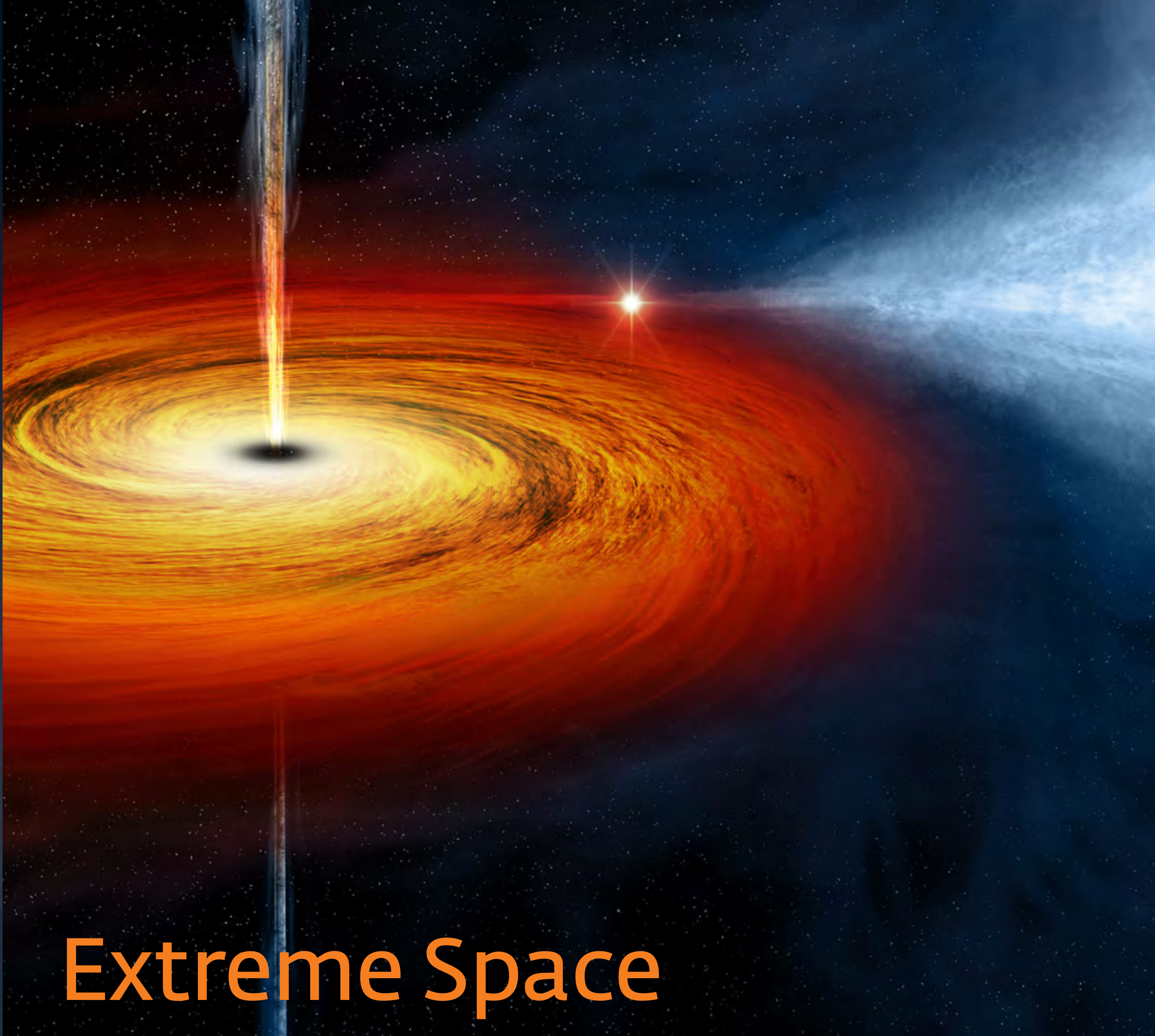

Extreme Space

PUBLIC FINANCE
Taxes That Vanish into Thin Air

BIOPHYSICS
Cells on the Catwalk

COAL RESEARCH
A Perspective for Life

LEGAL HISTORY
Ruling by the Book and the Cross


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Photo: Annelies Kusters

In the Streets of Mumbai

A modern metropolis in India: many different ethnic groups come together every day. A wide variety of languages can be heard, and very often, people who have no common language have to communicate with each other. People involuntarily resort to gesticulation, and their counterparts usually have no trouble understanding what is meant. But gestures can also be defined terms in a language of their own – the sign language of the deaf. Things get particularly interesting when sign language – here in its Indian form, of course – and spontaneous gestures are used in parallel and in combination. This is precisely what Annelies Kusters from the Max Planck Institute for the Study of Religious and Ethnic Diversity and her team are studying in the streets of Mumbai.

Kusters is interested in both the potential and the limitations of gesture-based communication. Being deaf herself, she makes it a point to involve deaf people in her research work. They can contribute greatly to these studies because they are very skilled in the creative use of gestures – both conventionalized and spontaneous – in conversations with the hearing as well as with other deaf persons.

The researchers observe and document the experiences of both hearing and deaf participants in conversations combining oral, gestural and written communication. And they also study what role the various surroundings play. It makes a difference, of course, whether a conversation takes place at the market, in a loud street, or in a quiet environment. Here, two researchers from Kusters' team watch a deaf businessman using facial expressions and gestures to negotiate with a hearing shop owner.

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18 EXTREME SPACE

ON THE COVER On a clear night, the starry sky appears calm and peaceful. In reality, however, all hell breaks loose in the heavens: stars absorb matter from other stars, suns explode and black holes greedily devour gas and dust. In short, there are a lot of extreme places in the universe – and they hold particular appeal for researchers.

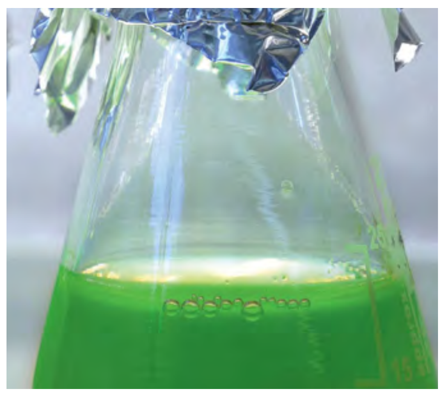
PERSPECTIVES

VIEWPOINT

FOCUS

Cover: Optical: DSS; illustration: NASA/CXC/M.Weiss; photos this page: NASA/ESA/Hubble Heritage Team (lg. image), picture alliance/Pacific Press Agency

56 On his head: Ben List does yoga almost every day – but in the lab, he does it solely for the photographer.



64 On the lookout: Researchers are testing various enzymes for synthetic photosynthesis.

70 On the wall: This fresco from 1338 warns against bad judges and unjust dominion.

Photos: Frank Vinken; MPI for Terrestrial Microbiology; Kunsthistorisches Institut in Florence – Max Planck Institute (left to right)

SPECTRUM

BIOLOGY & MEDICINE

MATERIALS & TECHNOLOGY

ENVIRONMENT & CLIMATE

CULTURE & SOCIETY

REGULAR FEATURES

Pearls for the Chancellor

Scientists present innovative projects to politicians

Interactive presentation: Martin Wikelski from the Max Planck Institute for Ornithology shows State Secretary for Economic Affairs Rainer Sontowski, German Chancellor Angela Merkel and Federal Minister of Research Johanna Wanka (left to right) the minute size of the transmitters with which he follows the wanderings of animals.

The presentation event with scientists from the Max Planck Society and the Fraunhofer-Gesellschaft was a first in two regards. On the one hand, the audience in the Max Planck Society's Harnack House in Berlin included prominent guests including German Chancellor Angela Merkel, Federal Minister of Research Johanna Wanka and State Secretary for Economic Affairs Rainer Sontowski. On the other hand, the researchers' presentations took on an unusual format: interacting directly with their guests, the scientists presented their work at a desk with a touchscreen. Under the motto "Pearls of Research for Practical Applications" they had to summarize their work in just a few minutes – succinctly and in an easily comprehensible manner. The gamut of topics ranged from virtual reality and forecasting earthquakes using animal sensors to the early detection of reading and writing problems and combating antibiotic-resistant germs. The concept proved a winning formula. The Chancellor praised the vivid, comprehensible presentation of the projects. In conclusion, she promised to continue to advocate for reliable financial framework conditions for research in Germany.

Threefold Leibniz Prize

Ralph Hertwig, Frank Jülicher and Joachim P. Spatz to receive Germany's highest scientific honor

When the German research community bestows the Gottfried Wilhelm Leibniz Prizes, each endowed with 2.5 million euros, there will also be three scientists from the Max Planck Society in attendance at the ceremony in Berlin in March. Ralph Hertwig, Director at the Max Planck Institute for Human Development, is receiving the prize for his pioneering research on the psychology of human judgments and decision-making. "This body of work is expanding our understanding of the capabilities and limits of human rationality," writes the jury. One of the world's leading scientists in the field of biophysics, Frank Jülicher, Director at the Max Planck Institute for the Physics of Complex Systems, will also be awarded the prize. As the jurors emphasize, he understands how to "elucidate the universal physical principles from the complex world of living matter." In addition, Joachim Spatz, Director at the Max Planck Institute for Medical Research, will be honored for his outstanding work at the interface between materials science and cell biophysics. Spatz studies cell adhesion, which deals with questions relating to how cells bind together and how they attach to surfaces.

Prizewinning trio: Joachim P. Spatz, Ralph Hertwig and Frank Jülicher (left to right)



Photos: David Ausserhofer (top), Tom Pingel, Norbert Michalke, Daniel Etter (bottom, left to right)

"Brexit will be more complicated than some imagine"

Jürgen Basedow explains why the British are facing arduous negotiations and why little will change initially

Jürgen Basedow

In June 2016, a majority of British citizens voted for the United Kingdom to leave the European Union. Upon taking office, the country's new Prime Minister, Theresa May, announced that she would quickly put the decision into practice. And she promised that "the power of EU laws in this country will end forever." Jürgen Basedow, Director at the Max Planck Institute for Comparative and International Private Law, believes that European laws will continue to apply in the UK for a long time to come.

Mr. Basedow, why can't the British – as a Tory MP put it – simply "offer to retain free trade, write a letter and leave?"

Jürgen Basedow: The United Kingdom has been a member of the European Union for 44 years. In that time, far-reaching contracts have been concluded and hundreds of regulations and directives enacted covering a wide variety of different areas. For example, there are extensive rules governing consumer protection in product liability, or the ban on misleading advertising, to name two cases. There are clear specifications in labor laws covering how workers' health must be protected, or the rights of works councils. There are common regulations on social security, environmental protection, insolvency proceedings, the certification of medicines, etc. If the British leave the EU, they will have to define what will replace all these standards.

Theresa May announced that she will introduce a "Great Repeal Bill" in the next session of the British parliament starting in May 2017. What does this entail?

First, it's a question of repealing the Act with which the country accepted the rules of the EU upon its entry in 1972. This has to be done at the time of the UK's departure. At the same time, the "Great Repeal Bill" is intended to convert European standards – that is, mainly EU regulations – into national law. This conversion is necessitated by the lack of time available: according to Article 50 of the Lisbon Treaty, countries have only two years to negotiate an exit. The clock begins ticking as soon as the British submit their official application to leave. If the negotiations haven't been concluded after 24 months and the deadline is not extended, all EU contracts and rules will cease to have legal force in England without it being clear what regulations will then apply. Theresa May wants to provide for this contingency.

If EU provisions are converted into British law anyway, what will change for the British?

Initially, this arrangement will give companies and citizens in the UK legal certainty. Later, parliament will decide whether all the standards will really be retained or what is to be changed. However, the difficulties for the British arise not in their own country, but in the remaining EU states. If the United Kingdom is no longer a member of the EU, British companies and service providers will lose many advantages on the continent. Lawyers, financial advisors, architects and many others will no longer be readily able to work in Germany, France or Sweden, for instance. The disadvantages will be most clearly revealed in the area of judicial rulings. The decisions of British courts will no longer be automatically recognized in EU countries. This will affect even such simple cases as a car accident and the question of which insurance company has to pay.

The British want to settle such matters during the exit negotiations ...

That depends on how long they wish to negotiate. If you look at the enormous volume of EU regulations, it certainly can't be done in two years. I would estimate that the negotiations will take eight or ten years – unless you take a ready-made model, namely the contracts with Norway, Iceland and Liechtenstein. However, all freedoms of movement apply in those countries – free movement of people, goods and capital and freedom of services. And the free movement of people also covers the right of establishment and the free movement of labor.

But that is precisely what the British don't want; they want less immigration.

That's why the subject of free movement will certainly be the most difficult point. Theresa May announced that "Norway is not a model." On the other hand, the EU won't budge from its freedoms of movement –of that I'm certain. So the Norwegian model might still come after all, at least as an interim solution if time is pressing. I can hardly imagine that the UK will talk about every single act of law – especially as the negotiations with the EU won't be the only ones.

What else is there?

The EU has concluded many international treaties with non-member countries that won't automatically continue to apply to the United Kingdom if the country leaves the EU. These include, for instance, agreements on liability in the areas of aviation, copyright and environmental protection, as well as many trade agreements. China announced that it is interested in concluding a free trade agreement with the United Kingdom and said at the same time that Britain should provide 500 people to work out the details. Not only does this show that Brexit will be much more complex than some imagine, it also underscores that the EU is more than a union of member states: it is a player on the world stage. That won't be so easy to replace.

Interview: Mechthild Zimmermann

Photo: MPI for Comparative and International Private Law

Welcome to Cyber Valley

Science and business forge research alliances in the area of artificial intelligence

At the launch in Stuttgart: Theresia Bauer, Minister for Science, Winfried Kretschmann, Minister President, Volkmar Denner, Managing Director of Bosch, and Martin Stratmann, President of the Max Planck Society (left to right)

Intelligent systems will shape our future: in the form of self-driving vehicles, household assistants or tiny robots in medical technology. In order to expedite this development, partners from science and business followed the initiative of the Max Planck Society and created Cyber Valley in the Stuttgart-Tübingen area. This ambitious project was kicked off in December by Winfried Kretschmann, Minister President of Baden-Württemberg, Martin Stratmann, President of the Max Planck Society and the other project participants. The Max Planck Institute for Intelligent Systems, the Federal State of Baden-Württemberg, the Universities of Stuttgart and Tübingen, and the companies, Bosch, Daimler, Porsche, BMW, ZF Friedrichshafen and Facebook want to strengthen research and development in the area of artificial intelligence in Cyber Valley. Together they are creating one of the largest research alliances in this field in Europe. Baden-Württemberg alone will invest more than 50 million euros in the project in the coming years.

Commitment to Scholars at Risk

Max Planck Society joins international network defending the human rights of scholars worldwide

The MPG is now a member of the "Scholars at Risk" (SAR) network, along with other prestigious international scientific facilities. The aim of the initiative is to support scientists around the world who are under threat from, for instance, war or violence. The network brings people and guest facilities together, but it also supports its 400 members with counselling and takes on the research work when evidence of the risk has to be provided for scholarship applications. The same is true of the Philipp Schwartz initiative by the Alexander von Humboldt Foundation (AvH), in which universities or even MPIs have until April 21 to submit applications for full 24-month scholarships for researchers at risk. Information and the application form are available on the AvH website. The point of contact at Administrative Headquarters for SAR is Barbara Spielmann, Coordinator for International Relationships.

The Scholars at Risk initiative condemns the implementation of U.S. President Trump's executive order on immigration.

Photos: State Ministry of Baden-Württemberg (top), Margaret Coons / Scholars at Risk (bottom)

Declaration of Principle on Animal Research

White paper emphasizes indispensability of animal research, as well as special ethical responsibility

The Senate of the Max Planck Society has adopted a white paper on animal research. It underscores that animal studies are indispensable in basic research, but it also acknowledges the special responsibility of every scientist, and subscribes to a culture of welfare. A further important concern is the transparent presentation of research to the public. The paper is the result of the extensive deliberations of a committee boasting an international line-up of well-respected researchers from the life sciences, as well as behavioral researchers, ethicists, specialists in communication and personalities from the field of research policy. In the future, the Max Planck Society aims to dedicate itself to the best possible implementation of the principles of the 3Rs. This stands for Replacement, Reduction, Refinement – the replacement and reduction of animal research and the minimization of stress for the animals. A fourth R for Responsibility completes the principles. For example, the sentience, consciousness and intelligence of different species of animals are to be investigated and animal research continually reassessed on this basis.

Protection from a single source: In the future, the Max Planck Society aims to promote a culture of welfare in animal research.

On the Net

Award-Winning Video
An international jury has awarded the Max Planck film *Biomaterials – Patent Answers from Nature*, which portrays the research conducted by Peter Fratzl at the Max Planck Institute of Colloids and Interfaces, the 2016 Technology Prize. The prize is awarded by the Goethe Institute from a selection of films shown at the annual Science Film Festival, which brings science to the screen: entertaining, creative, stimulating – and always instructive. Aiming to make insights from the natural sciences accessible to a broad public, it attracts considerable attention, above all in Southeast Asia, North Africa and the Middle East.
www.youtube.com/maxplancksociety

Female pioneers of science
On International Women's Days, three women Max Planck scientists celebrated the scientific accomplishments of three early female researchers – also highlighting the often daunting social obstacles these women had to overcome to persevere in their fields: Caroline Herschel, Ada Lovelace, and Sofia Kovalevskaya. Astronomer Caroline Herschel was the first woman to be honoured with the golden medal of the Royal Astronomical Society. Ada Lovelace is considered to have written instructions for the first computer program in 1848. Russian Sofia Kovalevskaya was to become the world's first female professor of mathematics. Read more on:
www.mpg.de/female-pioneers-of-science

Why We Research with Animals
The animal research portal of the Max Planck Society has been updated. Numerous articles, background information, statistics and multimedia content explain why animal research is indispensable for basic research today and doubtless in the future, which animals are used for research and how researchers live up to their responsibilities. The white paper on animal research and a flyer for the public relations work of the Max Planck Institutes are available for download there.
www.mpg.de/animal-studies-in-basic-research

Photo: Wolfgang Filser/MPG

Taxes
That Vanish into Thin Air

International corporations such as Apple, Starbucks and Amazon have for years successfully avoided paying tax on their corporate profits. Aided by tax competition between nations, they shift their money to countries that have low tax rates and that guarantee that only domestic profits will be taxed. Our author explains why it is far from easy for the international community to counter these tricks.

TEXT **WOLFGANG SCHÖN**

The announcement by the European Commission that it would oblige global player Apple to pay back taxes totaling more than 13 billion euros attracted some of the most prominent international press headlines in summer 2016. The recipient was to be the Republic of Ireland, where Apple had been "stashing" unusually high profits in its subsidiaries since the 1990s.

Word soon spread of a tax war against US corporations and the US tax authorities

It will come as a surprise to no one that Apple rejected this demand. It does, however, seem odd that the Irish tax authorities should decline to collect these taxes. Both sides – the tax authorities and the company – maintain that everything was above board (that is, Apple had paid all of the tax it owed). Can European law compel a state to levy taxes to which it attaches no importance?

The stir this case created even on the other side of the Atlantic clearly illustrates the global dimension of the problem. Word soon spread that Europe had declared a tax war on US industry and the US tax authorities. For years now, Amazon, Google and Starbucks have been confronted with similar proceedings. US politicians, in an outpouring of wrath, pointed out that Apple might well demand to offset additional taxes paid in Europe against its tax bill in the US.

In practice, the aforementioned 13 billion euros would vanish from the US budget and reappear in its Irish equivalent. Treasury Secretary Jack Lew, along with some leading voices in Congress, protested in unusually sharp terms, and some observers interpreted the subsequent report that the US Department of Justice was threatening Deutsche Bank with fines in the region of 15 billion dollars for capital market misconduct as another move in this dispute. >

Blackening their names: In autumn 2016, demonstrators in Dublin symbolically floated a black balloon in the shape of the Apple logo. They were protesting against the Irish government, which declined to call in 13 billion euros in back taxes.

Photo: picture alliance/Pacific Press Agency

In order to understand this conflict, one must first appreciate why Ireland is reluctant to enforce this payment – it's not as if the country is swimming in cash. The reason is that, for many years, Ireland has set great store by offering a reliable and investment-friendly tax system for global players. And integral to this self-image is a self-imposed commitment to abide by long-term promises.

Apple received just such a promise decades ago regarding the taxation of its Irish subsidiaries. The gist of this agreement is that these subsidiaries will be taxed only on the proportion of profits accounted for by their (small-scale) domestic output in Ireland. This excludes the (significantly higher) profits made by these subsidiaries resulting from the use of the Apple brand and technology in the European, African and Asian markets. These profits – it has been revealed – are not taxed anywhere: not in the US (because they are not paid over to the parent company in California) and not in Ireland (because they are not related to production in Ireland).

> State aid sanctions can be deemed to apply only if the tax authority fails to abide by its own rules

These corporate profits that are "parked" in no-man's-land between producer and consumer are known in international parlance as stateless income. It is estimated that, with the aid of this technique, US companies alone have more than two trillion dollars in cash holdings lodged with overseas subsidiaries (predominantly in tax havens).

In recent years – driven primarily by politicians, but also by non-governmental organizations – a variety of initiatives have been launched at both the national and the international level to counter these practices. As understandable as this uproar may be, however, it is proving difficult to identify where the actual evil-doing lies.

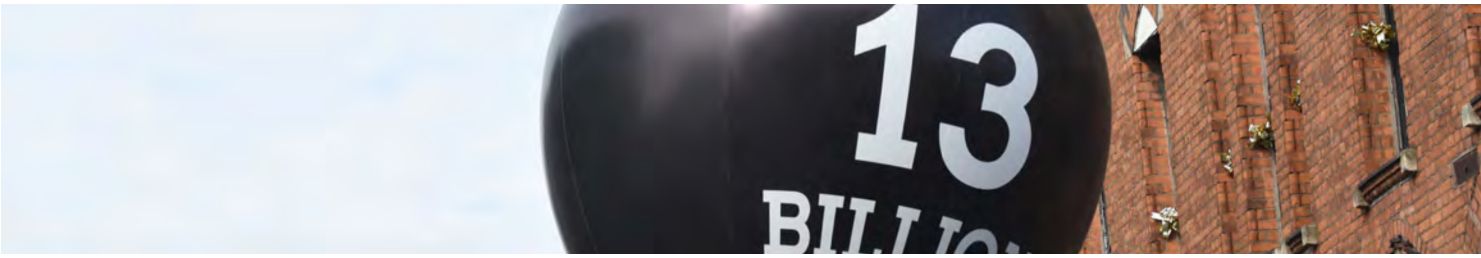
The first thing that comes to mind, of course, is the loss of tax revenues. When billions in profits aren't taxed anywhere, the corresponding tax income is missing in a national budget somewhere – but in which one? In Ireland? In the United States? Or should the profits be taxed where Apple's customers are located – for example in other European countries? Under the terms of the applicable tax agreements, however, these countries do not have the right to levy tax on profits on cross-border supplies. As a result, France, for instance, has called for Google and other companies to be taxed in the future on the basis of their "digital presence," but this proposal has not yet prevailed.

Is it not more a question of equitable taxation? Is this another instance in which, as so often, the rich pay nothing and the poor pay everything? This point of view is one that is emphasized again and again in civil society. The problem is simply that the contributions companies make to a country and its economy include not only their tax payments, but also jobs and investments. For this reason, countries are frequently willing to forgo a high tax take in order to attract companies to their shores.

So the "little man" can also be a winner. And who can blame a company for responding to such fiscal offers? Tax competition is intensified by the highly mobile nature of corporate functions: mobility of capital, mobility of intangible goods and services, mobility of management personnel. In this competition, the non-mobile factors – namely the workforce – can't keep pace.

This brings us to a third consideration, one that stirs the emotions: the competition between companies. The opportunity for multinational corporations to profit from the tax competition between countries strengthens their position relative to local competitors who are unable to enjoy such preferential treatment. The classic example here is the local bookseller who loses his customers to Amazon.

Amazon was long able to supply the German market with books via a subsidiary in Luxembourg without being subject to corporation tax in Germany – something the Munich-based firm of Hugendubel is



unable to avoid. This clearly highlights the relationship between the international tax system and the European rules on competition.

The German government made it clear years ago that one of the central purposes of its participation in the determination of international tax policies was to ensure a level playing field for market players both large and small. Similarly, in its decision on Apple, the Commission in Brussels was primarily concerned that Apple enjoyed tax treatment in Ireland that was out of step with the taxation of independent companies that don't form a part of international corporate structures.

The competition between states thus also impacts competition between companies. But there are limits to the use that can be made of European competition law: only if a national tax authority fails to abide by its own rules and regulations can state aid sanctions be deemed to apply under European law. As the US Treasury rightly points out, the European Commission has no authority to undertake any further standardization of international fiscal policy to suit its own interests.

Neither the phenomenon of tax competition nor its political fallout is new. In the 1990s, in particular, tax competition became a central topic of discussion among both economists and legal experts. Even before the turn of the millennium, the tax practices of tax havens and other preferential tax regimes had begun to pervade the realms of international politics. In 1998, the member states of the European Union agreed to a code of conduct that paved the way for the restriction or abolition of a wide range of preferential taxation treatment alternatives for foreign investors and business undertakings.

Also in 1998, the OECD published an influential report on harmful tax competition that still guides the political agenda today. This report accepts the existence of healthy tax competition, in which states compete by equitable means (primarily by reducing tax rates in general) for real investment and business activity. But it condemns harmful tax competition, as characterized for instance by preferential treatment for individuals, lack of transparency and deviation from recognized rules for calculating profit.

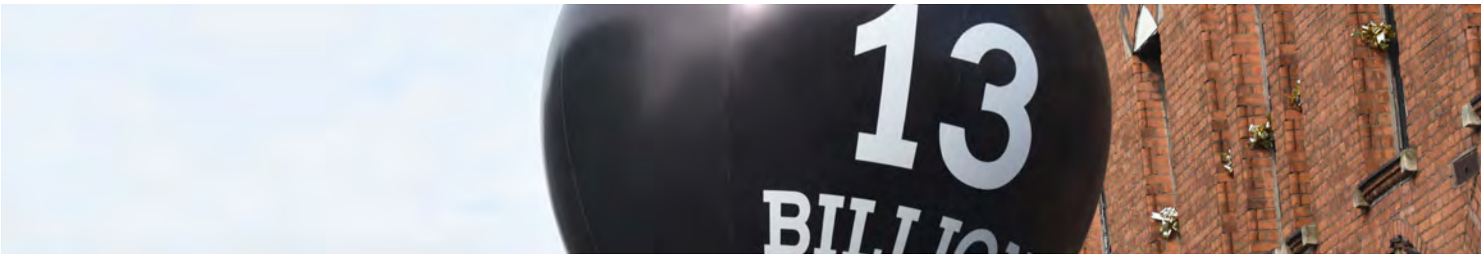
In the following years, however, discussion of international corporate taxation slipped into the background. After the turn of the millennium, it wasn't tax competition, but international tax evasion that occupied the global foreground. From the acquisition of CDs listing Germans' savings accounts in Switzerland, Luxembourg and Austria to the identities – revealed by a data leak – of those behind secretive Panama-registered companies, or even the tough sanctions threatened by the United States against banks the world over that refuse to disclose details of US account holders, all of these cases revolve around the unambiguously unlawful conduct of putative tax payers. Their guilt is as easy to assess as the identity of the state to which the unpaid taxes are due.

Corporations use the scope that countries offer them

New standards have made inroads in this area worldwide in recent years, as the international interchange of information has reached huge proportions in terms of both quality and quantity. The introduction in the coming year of a common reporting standard will enable over 100 countries to automatically exchange tax data. This has nothing to do with competition between companies – despite the unfortunate confusion consistently encountered in the political sphere.

It is only since 2012 that the issue of taxing international corporations has reappeared on the broader political agenda – but it has done so with unforeseen force and at multiple levels. At the national level, activity has been most in evidence in the United States and the United Kingdom, where special committees appointed by the Senate and the House of Commons – with strong support from civil society – have been examining the tax practices of large corporations and exposing these to the public eye. >

Photo: picture alliance/Pacific Press Agency



In Germany, the issue has been less prominent – given that the relatively high effective tax rate to which large German companies are subject is still regarded as a positive factor. At the international level, the members of the G20 seized the initiative and commissioned the OECD in Paris to prepare a report and an action plan on base erosion and profit shifting (BEPS) – that is, on the attempts planned by multinationals to reduce the potential bases on which tax can be assessed, and on the cross-border transfer of profits.

In an unparalleled intellectual and organizational masterstroke, by the end of 2015, under the umbrella of the OECD and with the participation of industrialized, newly industrializing and developing countries across the world, an impressive package of rules, minimum standards and agreements had been developed with the intention of placing international fiscal policy on a new footing. More than 100 countries are now engaged in implementing these resolutions.

> The question of where value creation takes place is not easy to answer

In parallel with this, the European Commission put forward numerous proposals to combat aggressive tax planning, some of which have since been adopted as binding directives by the Council of Ministers. The coming years will show whether these efforts to harmonize the rules of the game have been successful – with the process being assisted by a multilateral instrument that will enable thousands of double taxation agreements to be modified simultaneously.

If one takes a closer look at the BEPS initiative, it first becomes apparent that the perspective has changed. Whereas at the end of the 1990s the focus was clearly on regulatory competition between tax-gathering states, more recently it is the aggressive tax practices of large corporations that have been the subject of complaint. This adds to the debate a moral dimension that frequently impedes an objective analysis. Among other things, an answer is still lacking to the question of where to draw the line between acceptable and aggressive tax planning.

This approach also overlooks the fact that corporations, after all, can only exploit the scope that states have offered them in the first place. Without tax competition, there can be no tax planning – so if one wants to combat tax planning, one must first look at tax competition. Such competition is not easy to prohibit – what is needed instead is a consensus on common rules, that is, reconciliation between fiscal jurisdictions.

The BEPS project offers two principles for reorientation: the principle of once-only taxation and the principle of taxation on the basis of economic reality. However, both approaches suffer from blurred lines that could endanger the success of the entire undertaking. For example, inherent in the goal of once-only taxation is the idea that distorted competition between multinational and local companies can be prevented if it is assured that all corporate profits will attract a substantial rate of tax at least once. Such profits should not be parked somewhere free of tax in a tax haven, nor exempted from tax through the exploitation of regulatory differences.

The German government has made it a declared principle of its international fiscal policy to avoid double non-taxation, but this intention doesn't solve the problem of who should levy the once-only tax. Let us take the profits made by Apple in the European markets as an example: should these be taxed in the consumer states (where, as a general rule, the company has no fiscal presence)? Or in Ireland (where the subsidiaries are in fact registered, but maintain only minimal business operations)? Or in the United States (where the brand and technology were developed, but as yet no profit payments have been received)? It is obvious that none of the countries involved is making a serious effort to grab these profits.

According to the recent pronouncements of the G20, the OECD and the European Commission, on

Photo: picture alliance/Pacific Press Agency

the principle of "taxation follows value creation," the attribution of corporate profits and taxation rights should be determined by the location at which value is created. This should make it possible to effectively undermine the purely tax-driven transfer of profits to functionless companies situated in tax havens.

The program sounds convincing, but it has its limitations, given that the question of what economic reality means and where value creation takes place is not easy to answer. Where, exactly, is the source of Apple's billions in profits: California, where the brands and patents are developed? China, where the hardware is manufactured? Europe, where iPhones and iPads are purchased? Or indeed Ireland, where the relevant brand and patent rights are held by a subsidiary?

This isn't a question that can be answered strictly scientifically. As a successful export nation, the Federal Republic of Germany is keen for the location of production to have priority, whereas India, as a major importer of services, would wish to broaden its access to the corresponding profits made by foreign providers. Viewed globally, it is evident that, in recent years, the market states have managed some piecemeal expansion of their access to taxation. Tax competition supports this in that production may be relocated, but customers cannot.

At this point, it is apparent that the attempt to align international taxation with economic reality can ultimately lead to still more competition. The competition for the artificial transfer to profits is overlaid and replaced by still fiercer competition to attract actual business activities and investments. The latest political developments indicate that this competition is unlikely to cease.

Shortly after the Commission announced its decision in the Apple affair, the British government let it be known that, in the aftermath of Brexit, the United Kingdom would seek to heighten its profile as a tax-friendly location for investment – without the barriers imposed by European competition law. Whether, following Donald Trump's election victory, the United States will stand by the fiscal policy consensus achieved by the OECD remains to be seen – many important documents were in dispute even before the US presidential election.

The long-term strength of fiscal coordination is dependent on whether and to what extent nations perceive greater value in a global consensus than in individual political strategy. The coming years will provide an answer. The task of fiscal science lies in clearly identifying the premises and options for such strategies. ◂

THE AUTHOR

Wolfgang Schön, born in 1961, is Director at the Max Planck Institute for Tax Law and Public Finance in Munich. He also teaches at Ludwig-Maximilians-Universität München (LMU), where he is an honorary professor of civil, commercial, economic and tax law. His scientific work is focused on, among other things, the barriers to state tax sovereignty and the issues of tax and corporate law as competitive factors. Schön also serves as Chairman of the Board of the European Association of Tax Law Professors and Vice President of the German Research Foundation (DFG).

Photo: Axel Griesch

On the Trail of German-Israeli Cultural History

Max Planck scientists cooperate with partners in around 120 countries worldwide. Here they relate their personal experiences and impressions. For her doctoral thesis, art historian Anna Sophia Messner from the Kunsthistorisches Institut is tracing the life and work of female German-Jewish photographers in Israel – which has resulted in a variety of encounters between the past and the present.

My work in Israel is a bit like a treasure hunt. Every time I'm here, I discover new sources. Since completing my studies, I've specialized in German-Jewish cultural and art history. I'm particularly interested in artists who emigrated from Germany to Palestine in the 1930s. Due to the wealth of material, I had to narrow down the topic for my dissertation, and now I'm studying the life and work of German-Jewish photographers. Like numerous other German Jews, they had fled from the Nazis. Back then, there was a saying: "Do you come from Germany or from conviction?" There was certainly some truth to it. Many Germans held tightly to their German language and culture in exile and hardly identified with their new home at all. Some also later moved on to other countries, which is one of the reasons why the photographers were forgotten.

My field research took me to archives, museums and private collections. My research began with the sisters Gerda and Charlotte Meyer from Berlin, who opened a photography studio in Haifa in the mid-1930s. Their portraits were highly valued: they photographed famous personalities such as Arturo Toscanini, David Ben-Gurion and Golda Meir. In the

Graphic: iStockphoto

Anna Sophia Messner, 35, studied art history, Jewish history and culture, and classical archaeology at Ludwig-Maximilians-Universität München (LMU), and completed language programs at the Hebrew University of Jerusalem. She curated exhibitions at the Jewish Museum Munich and the city's municipal archives, and publishes on Jewish and Israeli artists. From 2012 to 2015 she worked as a scientific assistant at the LMU Institute for Art History. Since 2015 she has been working on her doctorate in connection with the Max Planck Research Group "Objects in the Contact Zone – The Cross-Cultural Lives of Things" at the Kunsthistorisches Institut in Florence.

1940s, they compiled documentation for industry, including for the Iraq Petroleum Company, which had refineries in Haifa. Both later left the country again, one to Canada and the other to England.

Since I started researching, more and more stories like this one have come to light. The photos and documents turn up in attics and basements, and sometimes even in garbage dumps. I have developed a network of Israeli colleagues who tell me when new material has been discovered. I also talk to relatives and contemporaries of the deceased, most of whom insist on speaking German with me. Even the children of the German emigrants frequently still speak their parents' language quite well, though the German may sound somewhat old-fashioned to modern ears – it's just how people spoke in Germany in the 1930s.

Life here in Tel Aviv is the same as in any other international metropolis. It's a bit like living in a bubble, because you don't usually hear too much about the Israeli-Palestinian conflict, which is definitely present in other cities. In Jerusalem's Old City, for example, there might be tensions particularly on religious holidays, especially around the Temple Mount. This is evident, for example, from the increased military and security controls around the city. Nevertheless, people in Israel try to lead a largely normal day-to-day life.

One question I'm frequently asked is how people treat Germans in Israel. I've had only good experiences. Particularly the third generation – people my age – are very open toward Germany. They're interested in the country their grandparents came from and are happy to connect with Germans. Some are even learning the German language. I have since built up a large professional network here and made friends. That's another reason I keep coming back to Israel.

Photo: Private collection

Frantic **Finish**

Supernovae portend cosmic catastrophes. When a massive star slides into an energy crisis at the end of its life, or a sun that has already died is overfed with matter, the end is an explosion of unimaginable proportions. What exactly happens here? **Hans-Thomas Janka** from the **Max Planck Institute for Astrophysics** in Garching wants to get down to the nuts and bolts. He simulates supernovae on the computer and makes them explode in the virtual world – meanwhile even in three dimensions.

TEXT **HELMUT HORNUNG**

On February 24, 1987, shortly after midnight, Ian Shelton is sitting in the darkroom of the Las Campanas observatory near the city of La Serena in Chile. The Canadian astronomer is developing pictures of the Large Magellanic Cloud, a neighboring galaxy of our Milky Way. As the images in the fixing solution become clearer and clearer, he immediately recognizes a bright star that doesn't belong there. Shelton goes outside into the clear night, looks up to the sky and discovers the spot of light in the Large Magellanic Cloud with his naked eye. The scientist knows immediately: what he is observing is a supernova, the closest one in 383 years.

"Supernova 1987A opened up a new chapter in research," says Hans-Thomas Janka. The scientist at the Max Planck Institute for Astrophysics has been studying this astronomical phenomenon for many years. It is by no means as far removed from our daily life as some would think, because the calcium in our bones and the iron in our blood originate from the nuclear melting pots deep in the interiors of the stars. These elements were released during large numbers of supernovae, and mixed with others to form the stuff that life on Earth was ultimately made on. Our existence is therefore closely connected with the cosmos via the most violent explosions since the Big Bang.

The zoo of supernovae is very diverse and confusing to the layperson. Astronomers have classified around a dozen different types of supernovae. However, "fundamentally, we differentiate between thermonuclear and core-collapse supernovae," Janka says. The criteria used are the lines of hydrogen, helium and silicon that occur in the spectra – that is, in the decomposed light – and also the shape of the light

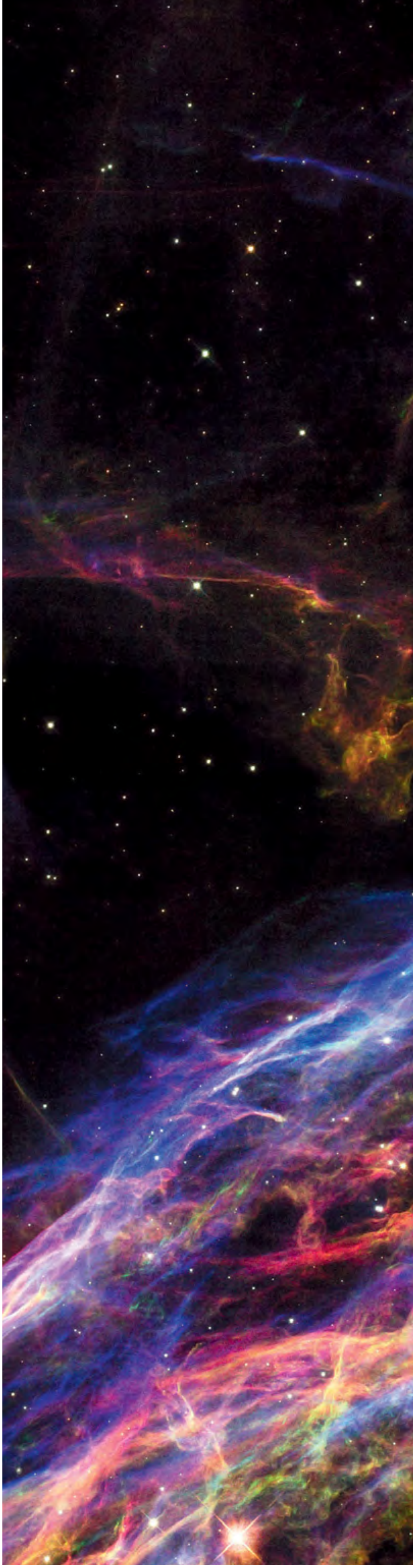
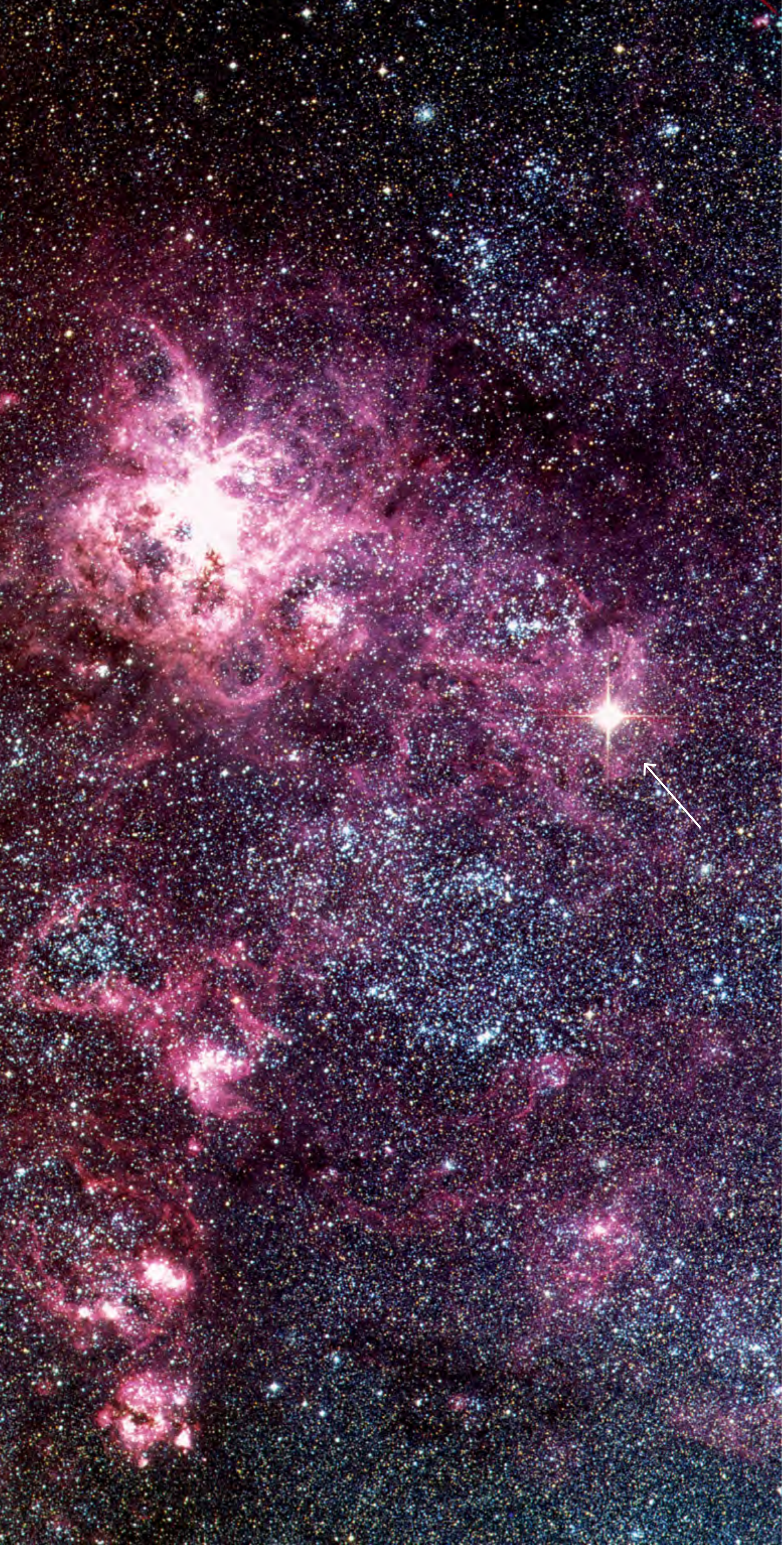


Photo: NASA/ESA/Hubble Heritage Team

The end of a star: Around 18,000 years ago, a massive sun exploded. At the site of the disaster, astronomers now observe the Cirrus nebula – gas that was once released by the supernova. The image shows a section of this cosmic web.



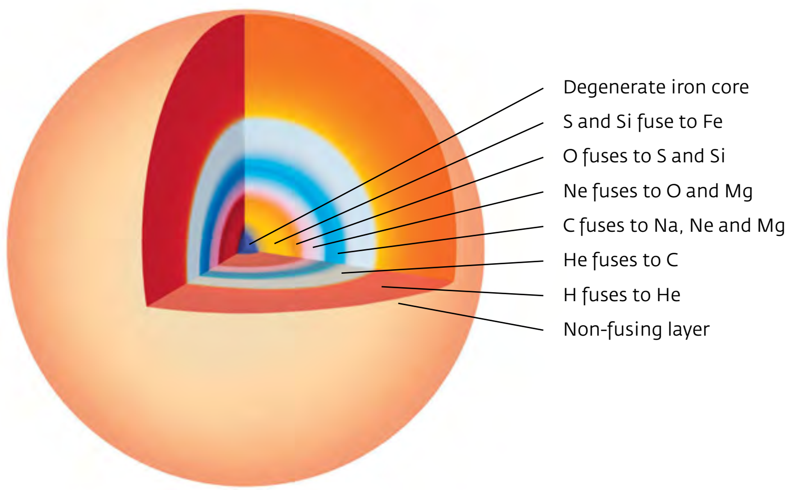
curves. The spectra of thermonuclear supernovae (Type Ia) have no hydrogen and no helium lines, but strong lines of the element silicon. According to one conceivable scenario, the explosion is caused by the “overfeeding” of a white dwarf, the burnt-out core of a sun of relatively low mass.

Such a stellar remnant sometimes has a partner star to which it is bound by gravitational forces. It is also gravity that enables the white dwarf to extract large amounts of gas from the surface of its partner. The matter flows onto the white dwarf, where it accumulates. This process, called accretion, causes the dwarf to constantly increase in mass. At some stage, its mass reaches around 1.4 solar masses.

If this limit, which is named for astrophysicist Subrahmanyan Chandrasekhar (1910 – 1995), is exceeded, the worst-case scenario becomes reality: the white dwarf begins to contract. This contraction releases gravitational energy, which heats the crystal-like mix of carbon and oxygen; in this phase, the star resembles an extremely compressed

Light shows in the sky: Supernova 1987A (arrow), taken shortly after its flare-up as a bright star in the Large Magellanic Cloud. The small image shows the remnant of the explosion just over ten years later; three bright rings are clearly visible.

Photos: ESO; Robert P. Kirshner and Peter Challis, Harvard University, STScI, NASA



Layers full of energy: Different nuclear burning processes occur in a massive sun. After the fusion of sulfur and silicon to iron, production stops. The sphere of iron in the core finally collapses further into a dense object – a neutron star or a black hole.

diamond. In its interior, the first step is the formation of islands in which thermonuclear reactions occur. Silicon and nickel are formed. The ignition sources spread at subsonic speed (deflagration) and burn from the center of the star outward toward its surface.

This causes instabilities, leading in turn to turbulence, which interacts with the thermonuclear flame and rapidly increases its surface area. Finally, a detonation wave builds up that propagates at supersonic speed and blows the ball of gas to pieces – a supernova explodes. “Unfortunately, it has not yet been possible to observe even a single precursor system of such an explosion directly, which is why we are still speculating about other possibilities,” says Hans-Thomas Janka.

This type represents only around one quarter of all supernovae observed, whereas most violent stellar deaths can be attributed to a single massive star (Type II). This means the precursor star has at least eight or nine times the mass of our Sun. The giant first spends several million years quietly and unspectacularly fusing hydrogen to helium. When the supply of fuel is exhausted, this is not the end by a long shot. Although the intense radiation means the star continuously loses energy, it compensates this deficit through the contraction of its interior – which results in a massive increase in pressure and temperature.

THE STAR BALLOONS INTO A GIANT

In this phase, the star increases its surface area: it balloons into a giant with a radius measuring a hundred to a thousand times that of the Sun. Its luminosity also increases considerably, now shining several million times brighter than the Sun. “The subsequent fate of the star is now decided,” says Janka. “If the temperature in the stellar core increases sufficiently, the ash from the previous fusion process can ignite.” Helium, for example, burns at around 200 million degrees Celsius to form carbon and oxygen.

At the end of this chain, stars with the stated eight or nine solar masses develop temperatures of 800 million degrees at their centers. The carbon fuses to sodium, neon and magnesium; neon to oxygen and magnesium; oxygen to sulfur and silicon. The star literally has a warmer and warmer glow around its heart. Above three billion degrees, the subsequent fusion steps follow one another at an ever-increasing speed. Within only a few months and then after only a few days, nickel, cobalt and finally iron are forged.

Now the end has been reached: since iron has the highest binding energy per nucleon, no more energy can be generated from its fusion. The structure of the star now resembles that of an onion: the core of iron slag is surrounded by layers of silicon, oxygen, neon, carbon and helium, with the hydrogen layer at the very outside.

The Chandrasekhar limit mentioned above, which the iron core now approaches, again plays a role in how the story continues. The density of the core has increased to 10,000 tons per cubic centimeter. Electrons are squeezed into the protons to form neutrons. This reduces the pressure inside the core, which now collapses in fractions of a

Illustration: Christoph Schneider based on a diagram by Achim Weiss – MPI for Astrophysics second to an object of 10,000 times greater density: a neutron star. But it can get even denser still. If the core has a large initial mass, a black hole forms at the center of the dying star.

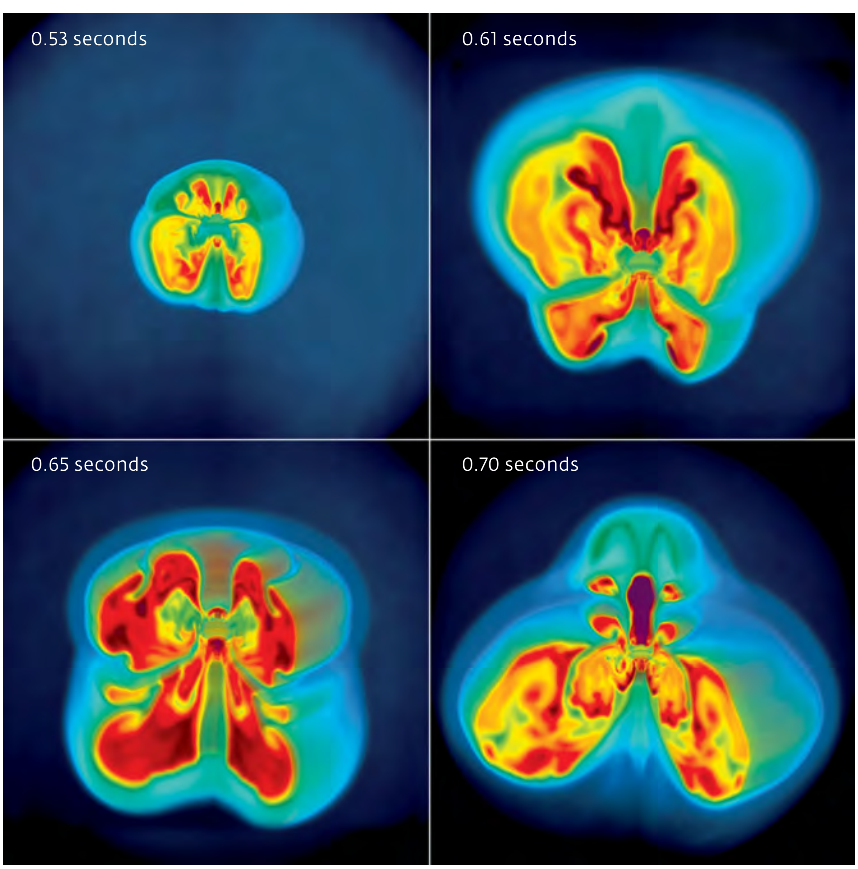
THE FRAGILE EQUILIBRIUM IS SEVERELY DISTURBED

In any case, the inner layers of the star plunge unceasingly onto the massive central object. The delicate hydrostatic equilibrium has already been severely disturbed for some time – the interplay between the outwardly acting gas and the radiation pressure, and the inwardly directed gravitational pressure. The latter inevitably compresses the star even further. The impact of the matter at supersonic speed does not go well for long: a shock wave builds up and travels from the inside to the outside and rips apart the stellar gas envelope with speeds of up to tens of thousands of kilometers per second – a supernova flares up.

Or maybe not? "If only it were that simple," says Hans-Thomas Janka. When the astronomers considered the scenario in greater detail, they found that there is no way the shock wave can cause the explosion directly by means of a purely hydrodynamic rebound mechanism. "Such a shock alone turns out to be much too weak. It isn't able to balance the massive energy loss from the center on the long journey through the collapsing stellar layers," explains the Max Planck researcher. In short, "after only 100 to 200 kilometers, the shock loses its power, it gets stuck in the star's iron core."

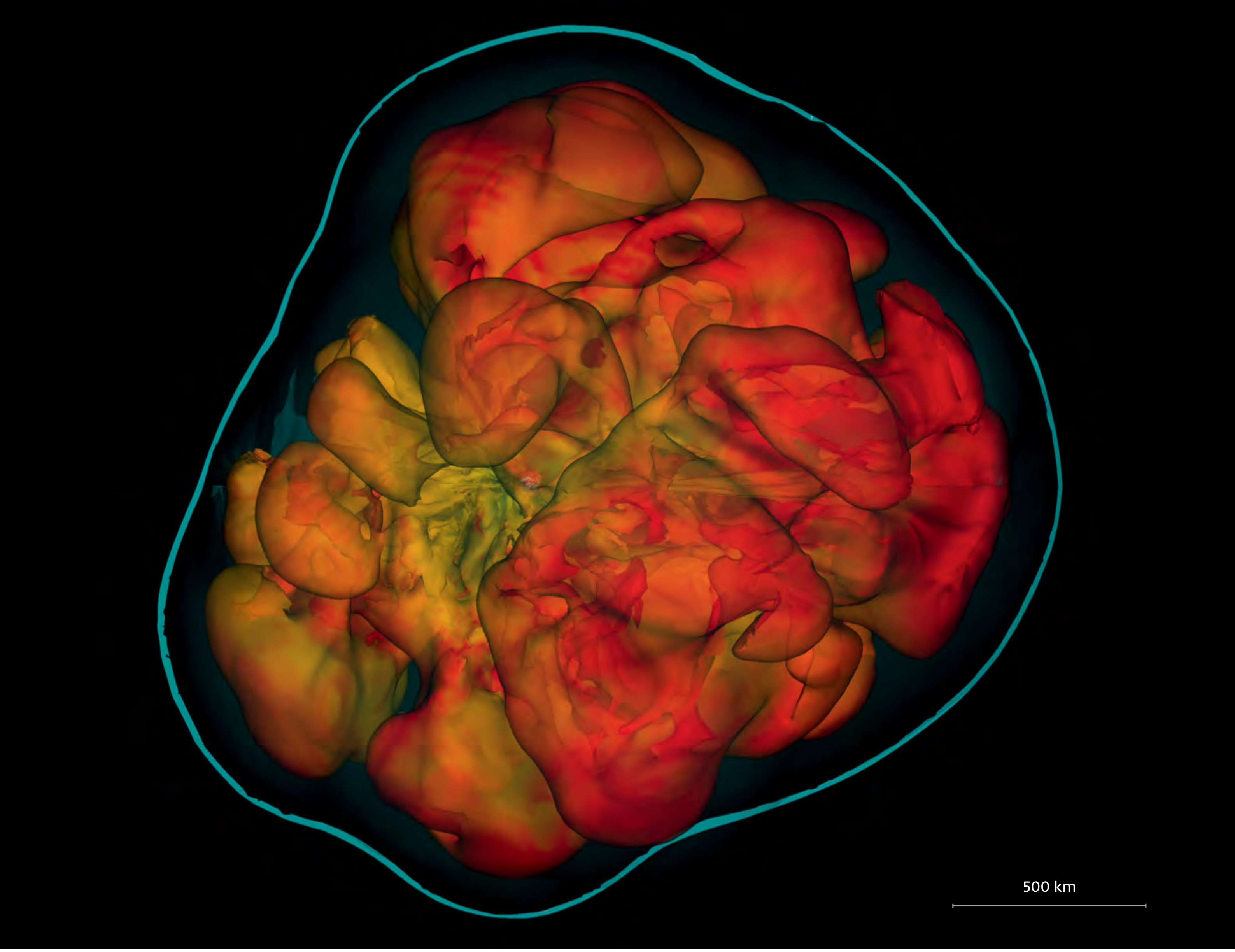
So what acts as the driving force? As early as the mid-1960s, scientists were bringing another engine into play: neutrinos. These nearly massless particles succeed almost effortlessly in penetrating practically anything that gets in their way – like our thumbnail, through which more than 66 billion of these elusive phantoms race every second. That they also play a role in supernovae has been known since the events of February 24, 1987. That was the day the explosion of a star called Sanduleak -69° 202 with a mass of 15 to 20 solar masses was observed from a distance of some 166,000 light-years. Around three hours before the visible light flash from the Large Magellanic Cloud, several neutrino observatories around the world registered two dozen of these ghost particles.

Although all later supernovae were much too distant to measure such neutrinos, this finding bolsters the theoretical assumption. "After a decade of development work, the 1980s saw researchers succeed in describing the mechanism of neutrino transport," says Janka. It was found that the particles manage to leave the interior of the star at the speed of light after stumbling about in it for several seconds. And, according to Janka, they are able to carry vast amounts of energy with them.



Explosion on the computer: A star of 15 solar masses is disrupted and gives rise to violent turbulence in the process. There is already a neutron star at its center; the seconds in the four partial images refer to the time after its formation. The explosion is asymmetric and is driven by the energy transfer of neutrinos. The diameters of the bubbles of matter (yellow, orange, red) range from 300 in the first to 600, 800 and 1,500 kilometers in the last image.

Computer graphic: Andreas Marek, Hans-Thomas Janka – MPI for Astrophysics



Computer graphic: Elena Erastova and Markus Rampp, Max Planck Computing and Data Facility (MPCDF)

Seething ball of gas: This computer simulation from 2015 shows the end of a star of 20 solar masses in three dimensions – and with it, the progress that has been made in research: the sequence on page 22 is around ten years older and was still a two-dimensional computation. The outer, bluish line in this image indicates the shock wave of the supernova.

As the stellar core collapses to a neutron star, the gravitational energy converts into internal energy of the matter, which in turn produces vast numbers of neutrinos. These heat the electrically conductive gas (plasma) around the neutron star and give the shock wave renewed power. The efficiency of this process is surprising: "American astrophysicists Stirling Colgate and Richard White argued that only 1 percent of the neutrino energy needs to be deposited by neutrino heating to ignite a supernova," says Hans-Thomas Janka.

In the 1980s, theoreticians began to simulate supernovae on the computer – and were disappointed. The stars simply wouldn't explode properly. Was the neutrino heating inefficient after all? It was soon suspected that the failure was more likely due to the models used – Janka's specialty. "At that time, they still had spherical symmetry – that is, they were one-dimensional." But then came Supernova 1987A. "We learned from observations that a high degree of asymmetry had to be present when it exploded," the scientist recalls.

GAMMA LIGHT BECOMES VISIBLE AFTER ONLY A FEW WEEKS

A thorough mixing evidently must have taken place during the explosion. This means that elements that had been deep inside the dying star suddenly moved toward the outside – nickel, for example, which was ejected far into the outer layer and radioactively decayed into cobalt. "We had actually expected that it would be more than a year after the explosion before we would observe gamma quanta, which originate from the decay of cobalt. But they turned up after just a few months," says Janka. We then knew that, in reality, it isn't as simple as the idea of layers of onion flying away.

As computers became ever more powerful, the theoretical scenarios, too, became increasingly complex: in the early 2000s, Janka and his colleagues worked meticulously on two-dimensional models whose stars possessed axial symmetry. The researchers now took very accurate account of interactions between the neutrinos and the stellar plasma, as well as convective mass motions and turbulence. "In fact," says Hans-Thomas Janka, "in these simulations, the symmetry is destroyed as soon as the explosion begins. Hydrodynamic, turbulent fluctuations occur, similar to convective flows in the Earth's atmosphere."

Janka's then-doctoral student Andreas Marek generated the first complete two-dimensional supernova model at the Max Planck Institute for Astrophysics between 2003 and 2006. The Institute purchased a 128-core computer especially for this purpose and installed it at the neighboring Garching computing facility, where it was used solely for this simulation – which was successful: "The supernova exploded!" says Janka. The effort had paid off – as had the efforts of Janka and his doctoral student Markus Rampp: the researchers wrote the extremely complex program codes for the computer simulation. These algorithms were intended to improve the neutrino transport. Janka doesn't want to go into detail, but when he talks of "three-dimensional equations with spatial coordinate and momentum space," even the layperson quickly realizes that these matters are fairly complicated.

This is all the more true for three-dimensional simulations that only became part of the scientists' repertoire in the last few years. The computing power required is enormous – 16,000 processors have to work in parallel for months to compute one model. This would take a single, modern PC 8,000 years. What it boils down to, according to Janka, is this: explosions driven by neutrinos also occur in 3-D. But the astrophysicist states two clear objectives that he and his colleagues will be striving to achieve in the future with the three-dimensional computations: "We want to use fully self-consistent simulations and all relevant microphysics to confirm the explosion mechanism quantitatively for many stellar masses. And we want to compare the models with the observations."

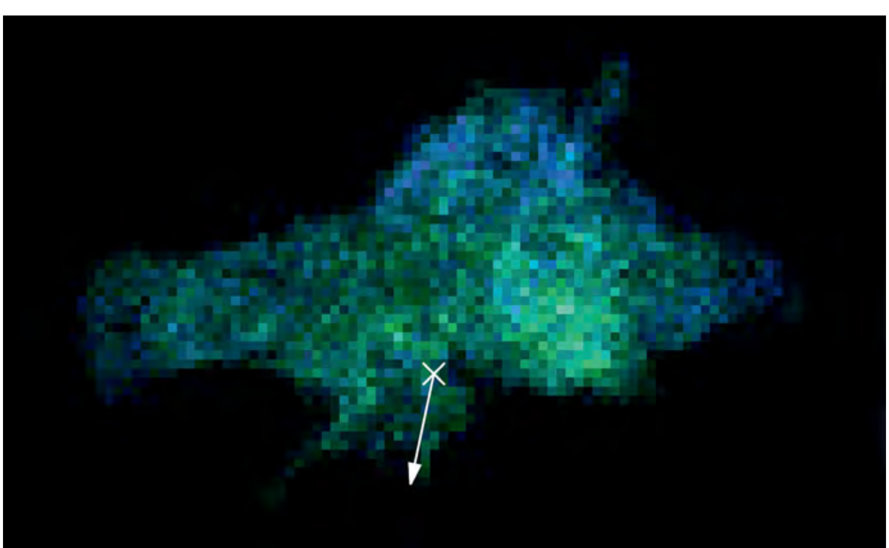
ULTRABRIGHT EMITTERS KEEP THE ASTRONOMERS GUESSING

It could then also be possible to solve a mystery that has increasingly moved into the research spotlight in recent years: ultrabright supernovae, or superluminous supernovae, as astronomers call them. The scientists observed the first example of this type in 2010. Although they sight more than 1,000 stellar explosions in total every year, only a few dozen of these tremendously bright emitters are known, which are up to 100 times as bright at their maximum as conventional Type II supernovae. The problem is: "These objects are all extremely far away. We can often register only the light curves, and the spectra are not conclusive in detail," says Hans-Thomas Janka.

What causes these supernovae? The researchers can only speculate. After an initial explosion, a magnetar, for example – a neutron star with an extremely strong magnetic field (MaxPlanckResearch 1/2017, page 26 ff.) – could become involved to drive this explosion further and amplify it enormously. The second possibility is that the shock wave of the supernova propagating outward interacts with dense matter shed by the star before the explosion.

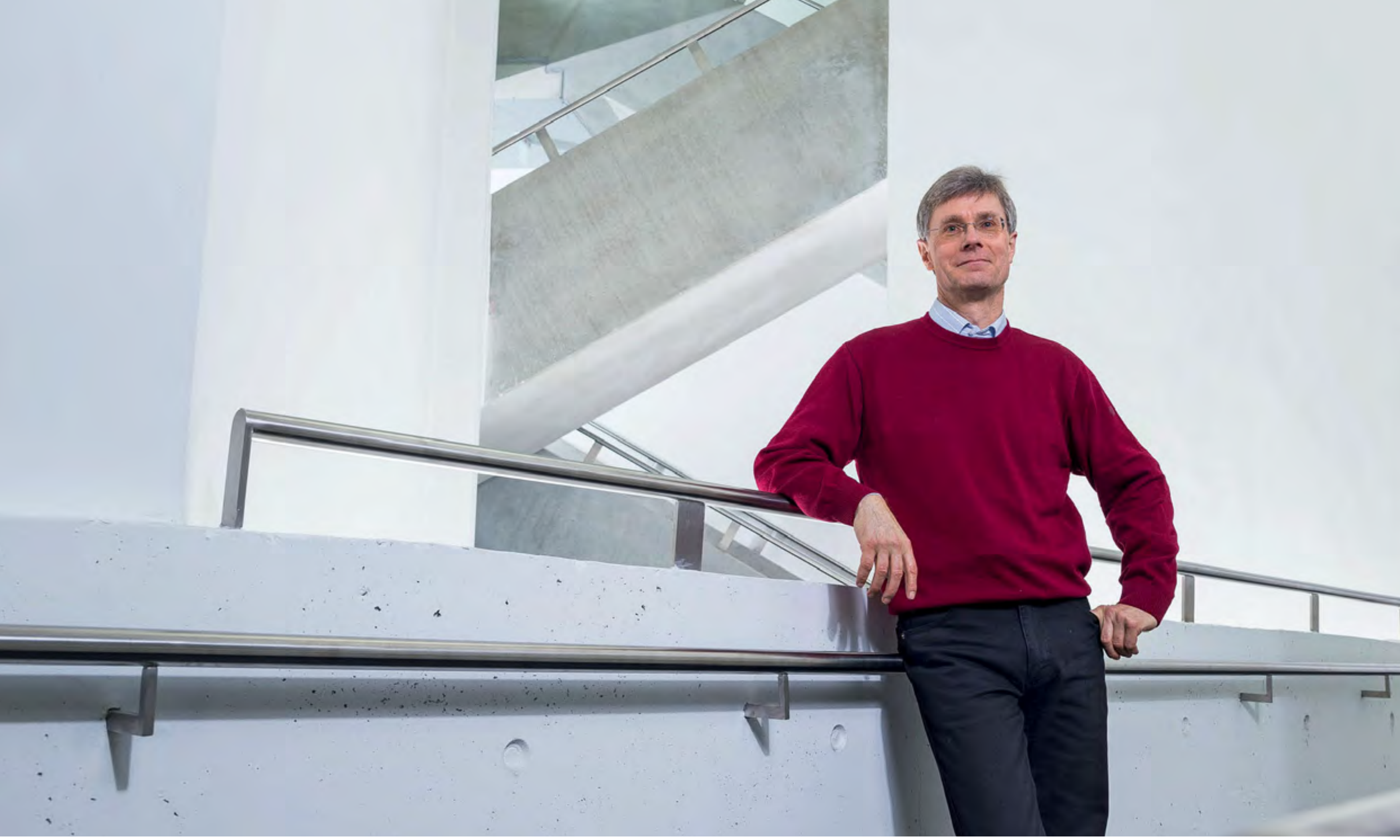
As a further alternative, the scientists consider so-called pair instability supernovae. This scenario is based on a star with 100 to 200 solar masses or even more. Such a heavyweight has a brief life and collapses as soon as it reaches the stage at which carbon fuses in the center. At temperatures of one billion degrees, photons with very high energies start to spontaneously convert into electrons and their antiparticles, the positrons. This "pair formation" leads to a rapid drop in radiation pressure – gravitation gains the upper hand, the nuclear combustion of carbon and oxygen accelerates at an explosive rate and the star could become a supernova.

Astronomers still don't know which of the three scenarios is the right one. They know from investigations of the light curves that superluminous supernovae apparently don't always release the incredibly large quantities of nickel – several tens of solar masses – that would be expected from pair-instabil-



Stellar kick: The neutron star (white cross) left behind by the supernova experiences a kick in the direction (arrow) opposite to the stronger side of the asymmetric explosion. Elements such as titanium and nickel (blue and green) are produced in greater amounts in the hemisphere that points away from the direction of neutron star motion. The astronomers observe this geometry for supernova remnants in space – in perfect agreement with theoretical models such as this simulation.

Computer graphic: Annop Wongwathanarat et. al, arXiv: 1610.05643



Supernovae in his focus: Hans-Thomas Janka from the Max Planck Institute for Astrophysics in Garching studies the largest explosions in the universe since the Big Bang. To investigate the physics that determines these events, Janka develops theoretical models based on complex computer programs.

ity supernovae. A viable theory must provide an adequate explanation of this fact.

Nickel is also the topic of Janka's most recent work, which has just been published in the ASTROPHYSICAL JOURNAL. It deals with what dying stars leave behind – supernova remnants. Observations and measurements of high-energy radiation at X-ray and gamma wavelengths with satellite telescopes such as NuSTAR and Integral show that radioactive elements such as titanium-44 and nickel-56 contained in the ejected material are not distributed symmetrically around the remnant neutron star.

According to the theory, this is because the compact stellar object receives a kick into the opposite direction of an asymmetric explosion – with consequences for the immediate cosmic environment: "The radioactive elements should have been explosively produced predominantly in the hemisphere of the massively deformed gas remnant that is opposite to the direction of motion of the neutron star," says Hans-Thomas Janka. That is what the theoretical 3-D models forecast. And that is precisely what the telescopes have discovered in nature, to the delight of the researchers: in the Cassiopeia A remnant and, so the prediction, probably also in what remains of Supernova 1987A. The latter therefore still turns out to be a lucky break for science, even though it is now 30 years since it flared up. ◂

TO THE POINT

- **Some stars meet a spectacular end as supernovae. The dozen or so different types that have been observed can be classified into two theoretical groups.**
- **In the case of supernovae of Type Ia, the probable scenario is that a white dwarf fed by a companion explodes; in the case of all other types, it is a massive star whose core collapses.**
- **The researchers found that the neutrino-heating mechanism plays a crucial role in the explosion of core-collapse supernovae.**
- **Astronomers today use complex three-dimensional models to simulate the physical processes in supernovae and can put several aspects of the theory to a test with the aid of actual observations.**

GLOSSARY

Antiparticles: As far as is known, nearly every particle has an antiparticle that is identical in terms of mass, lifetime and spin. In contrast, electric charge, magnetic moment and all charge-like quantum numbers are equal in magnitude, but have the opposite sign. The positron, for instance – the antiparticle of the electron – has a positive charge.

Plasma: A mixture of neutral and charged particles (partially ionized) or only charged particles, such as electrons and atomic nuclei (completely ionized), that is also called the fourth state of matter. Plasmas frequently occur at high temperatures. Stars consist of hot gas and plasma, for example.

Photo: Axel Griesch

Traps **in Space-Time**

Black holes are a permanent fixture in science fiction literature. In reality, there is hardly a more extreme location in the universe. These mass monsters swallow everything that ventures too close to them: light, gas, dust and even entire stars. It sounds quite simple, but the nature of black holes is complex. **Maria Rodriguez**, Minerva Group Leader at the **Max Planck Institute for Gravitational Physics** in Golm, wants to solve some of the puzzles these exotic cosmic bodies present.

TEXT **FELICITAS MOKLER**

For a long time it seemed that they existed only in the minds of theoretical physicists – black holes. But since at least a year ago now, we finally have clarity: they really do exist. On September 14, 2015, gravitational waves caused space-time to oscillate to a measurable extent in the American LIGO detectors for the first time.

The detection of the undulation of space-time predicted 100 years earlier by Albert Einstein (1879 to 1955) is simultaneously deemed to be experimental proof of the physical existence of black holes. The first measured signal GW150914 originated from two black holes with 36 and 29 solar masses, respectively, that used to orbit one another in a kind of binary star system until they finally merged into one object with 62 solar masses. Only a few months later, the researchers registered gravitational waves of source GW151226 from a similar system. These events gave the space-time structure a violent shake – and provided impressive confirmation of the existence of the mass monsters. (MaxPlanckResearch 2/2016, page 78 ff.)

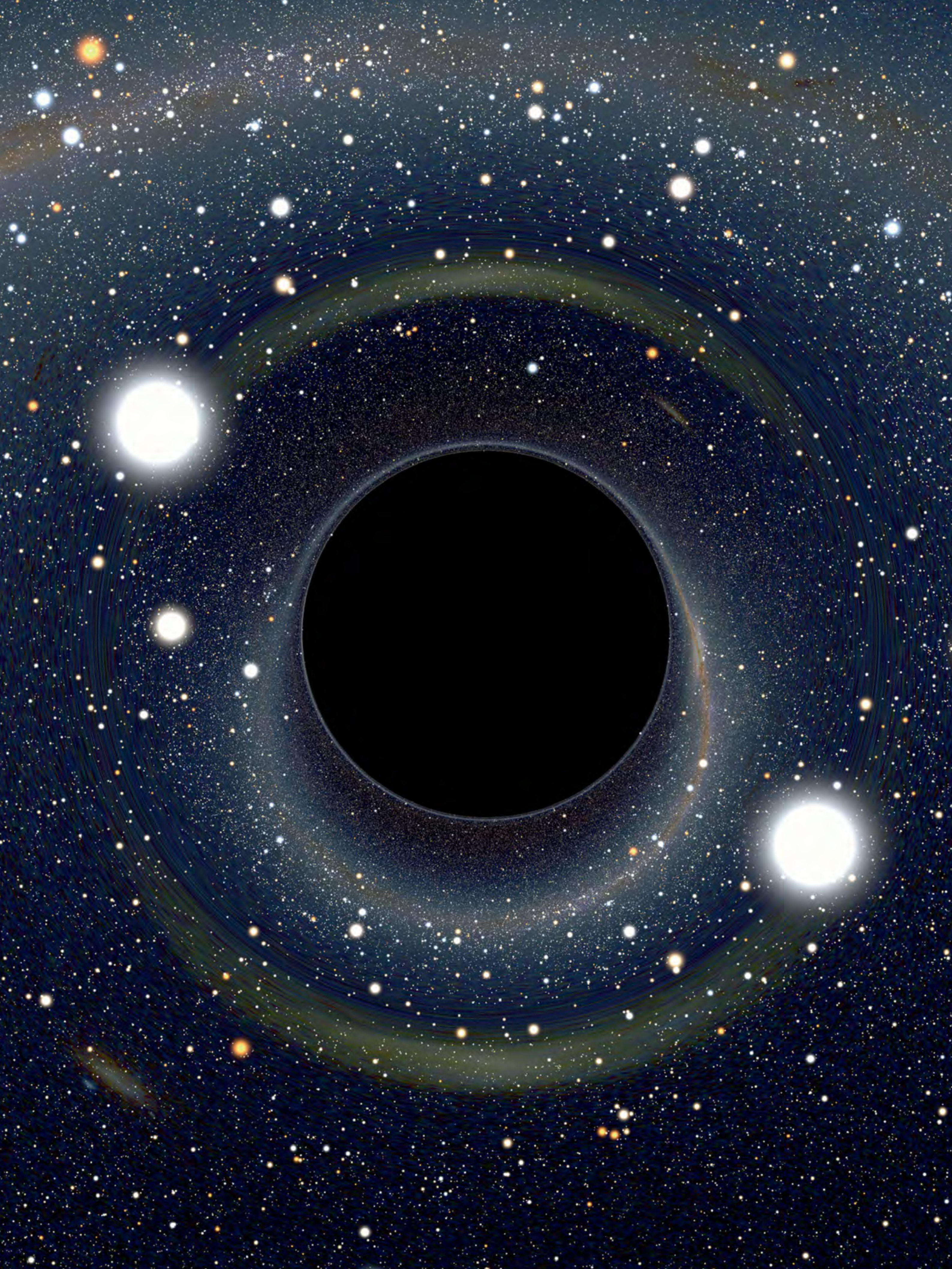
EINSTEIN'S THEORY REPLACES THE CLASSICAL CONCEPT

Naturalists John Mitchell (1724 to 1793) and Pierre Simon de Laplace (1749 to 1827) were already speculating in the late 18th century about dark stars or dark astrophysical bodies whose gravity was so strong that light couldn't escape them. The ideas of the two researchers were still within the framework of Newtonian gravitational theory and the corpuscular theory of light.

At the beginning of the 20th century, Albert Einstein revolutionized our understanding of gravitation – and thus also of matter, space and time – with his general theory of relativity. His idea replaced the classical concept of gravity as the direct interaction between two masses that move through rigid, Euclidian space. Instead, it held that three-dimensional space and time are united to form a four-dimensional space-time and are themselves now deformable and dynamic. A mass such as the Sun bends space-time in its vicinity – the larger and, in particular, the denser a mass, the stronger the effect.

The motion of a second, smaller mass, such as a planet, then follows this curvature. If the local curvature chang-

Under the spell of gravity: Black holes have been keeping astrophysicists busy for more than a century. None has yet been observed directly, but the discovery of gravitational waves at least shows that these bizarre structures really do exist.



es because a mass accelerates across this space, this change propagates at the speed of light as a gravitational wave in the space-time structure.

Einstein used Riemannian geometry as the mathematical basis for dynamic space-time. Black holes emerge from the field equations, which describe the curvature of space brought about by matter and, conversely, the effect of curvature on matter, as a natural solution for matter concentrated at one point. The gravity there is infinitely large, and space-time has an infinitely large curvature: mathematically, it is a singularity.

"Physically, however, such infinities don't tell us anything," says Maria Rodriguez. "What is relevant is the separation from the point mass below which gravity becomes so strong that nothing can escape from it and can only fall into the black hole," says the Minerva Group Leader at the Max Planck Institute for Gravitational Physics in Golm.

There is no escape for either matter or light. This is what makes it so difficult for astronomers to observe these objects. The explanation is simple: in order to leave a conventional celestial body such as Earth, objects require a minimum kinetic energy that depends on the body's mass. The velocity that rockets require, for example, is called the escape velocity. For a black hole, this velocity corresponds to the speed of light.

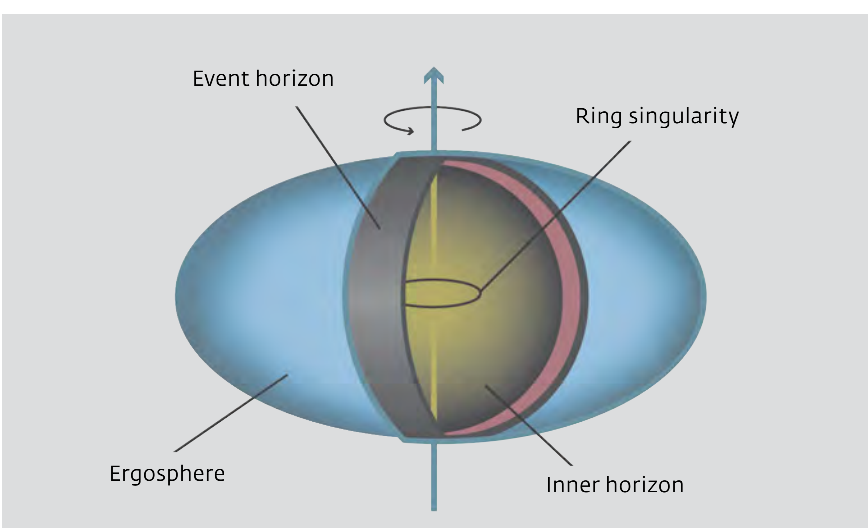
GRAVITY EVENTUALLY GAINS THE UPPER HAND

How space-time behaves under these conditions was first described in 1916 by astrophysicist Karl Schwarzschild (1873 to 1916) in the metric that bears his name. The so-called event horizon that shields the interior of the black hole from the outside world is defined by the Schwarzschild radius, which depends on the mass. "Its shape is a perfect sphere for conventional black holes, which don't rotate and have no electric charge," says Rodriguez. The researcher investigates the boundary surfaces of black holes with different properties.

But black holes with no angular momentum are probably very rare in nature. This is because these objects are formed, for instance, when particularly massive stars have exhausted the supply of fusionable material in their interior toward the end of their life. The temperature there then drops and thermal and radiation pressure are no longer sufficient to counteract the star's gravitation.

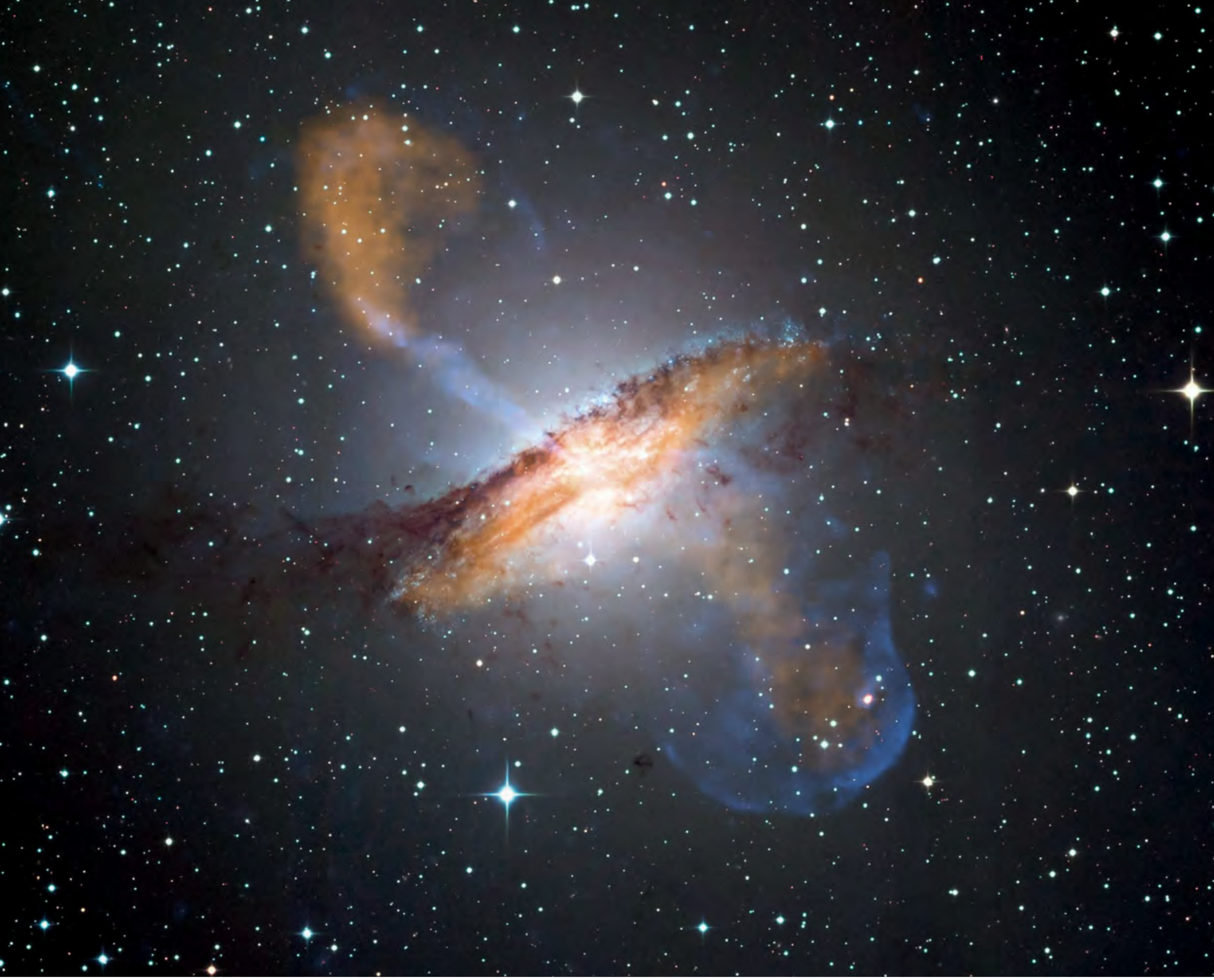
The stellar interior implodes and the once free electrons are pushed into the positively charged atomic nuclei. In such a supernova, the neutrinos released in this process transport a large portion of the energy away and hurl the outer stellar shell into space. The matter in the core, in contrast, contracts more and more under its own gravity. If the original mass of the star was more than eight solar masses, the ultimate result is a black hole. Since stars usually rotate about their own axis and the angular momentum is conserved, they pass it on to the black hole.

Astronomers are still puzzled by the birth of the particularly massive black holes – with a few million to a billion solar masses – that are presumed to lie at the centers of galaxies. They may possibly have formed from the first generation of extremely heavy stars that, having become a black hole, rapidly accreted more and more mass and thus more and more angular momentum.



Clear structures: The physics might be complex, but the explanation of the structure is simple. The graphic shows a rotating black hole with a ring singularity in the center and the inner horizon. The event horizon is something like the surface of the black hole; when something disappears behind it, it is truly out of this world. The ergosphere marks the region in which every object is forced to co-rotate.

Graphic: designergold, based on original material from the MPI for Gravitational Physics



Engine at the center: Centaurus A is around 15 million light-years away, making it the nearest radio galaxy, but it also emits intense X-ray and gamma radiation. The jet structure visible in this image is apparently caused by the activity of the central black hole with around 55 million solar masses.

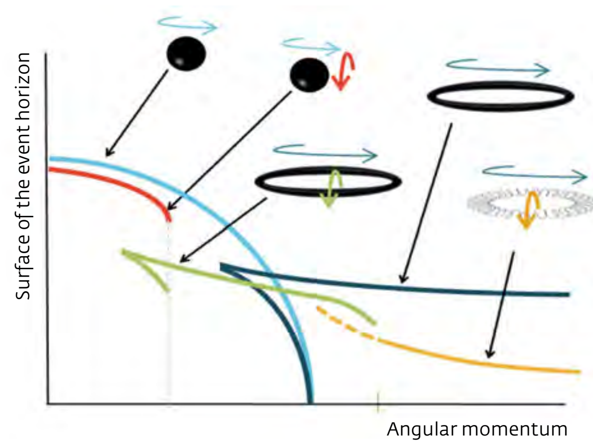
The hypothesis of so-called primordial black holes, according to which these cosmic heavyweights formed shortly after the Big Bang together with the first galaxies, is also being discussed. Astronomers also speculate about the existence of medium-weight black holes, with 100 to one million solar masses, that could be present at the centers of large globular clusters.

PARTICLES ARE EJECTED

When a black hole rotates, its event horizon deforms slightly. Furthermore, the space-time of its immediate vicinity and the matter located there rotate with it. This sphere of influence of the black hole is called its ergosphere and is ellipsoid in shape. Matter from outside that gets caught up in it doesn't necessarily plunge directly into the space-time trap, but rather initially co-rotates with it. Nevertheless, it is unable to escape from it.

"Unless the matter is electrically charged," says Rodriguez, because the co-rotating charged matter causes a magnetosphere to form. Some of the charged particles are deflected along the magnetic field lines. Depending on the sign of the charge and the orientation of the field lines, the particles then fall more rapidly into the black hole – or are ejected along the rotational axis. "Astronomers have since observed very high-energy jets in around 20 active galaxies or quasars. These objects probably have an extremely massive, rapidly rotating black hole at their center," says the Max Planck researcher.

To be able to correctly interpret these phenomena, the researchers are attempting to compute the behavior of rotating black holes and the physical processes in their immediate vicinity according to the laws of the general theory of relativity. Analytically, they have initially succeeded in doing this only for very slowly rotating black holes, but Maria Rodriguez is interested in the very opposite: objects that rotate about their own axis at almost the speed of light. >



Advanced mathematics: During her time as a postdoc at the Max Planck Institute for Gravitational Physics (Albert Einstein Institute, AEI), Maria Rodriguez computed possible surface configurations of event horizons of black holes in more than three spatial dimensions. The diagram depicts analytical solutions for five dimensions. Their shapes depend on mass and rotation (angular momentum). Depicted are the projections of the configurations from five to two and three dimensions.

To this end, she solves the equations of electrodynamics and, simultaneously, the field equations of the general theory of relativity on the basis of one and the same formalism. "The solution can be found either by trial and error or by adopting a systematic approach," says Rodriguez. "We used a method from string theory."

This theory originated in the 1960s. At that time, particle physicists discovered that the building blocks (nucleons) of an atomic nucleus are themselves composed of quarks. The scientists attempted to use string theory to unify the strong force, which keeps the quarks together to form protons and neutrons, with the weak force and the electromagnetic force. Quantum chromodynamics ultimately turned out to be more suitable for describing the strong force.

However, scientists later returned to string theory in order to unify gravitation with the other three fundamental forces. In addition to the four dimensions of space-time, it introduces six further spatial dimensions. "This is quite compatible with the concept of the general theory of relativity, since it doesn't specify the number of spatial dimensions at all. The four dimensions of space-time form a purely heuristic basis," says Maria Rodriguez.

AN ANT IN A CABLE KNOWS ONLY ONE DIMENSION

The reason we can't perceive these additional dimensions – if indeed they really do exist – could be that they are either particularly tiny or particularly large. "An ant, for example, that crawls through a cable will register only the direction straight ahead and experience its world as one-dimensional," says Rodriguez. Two additional dimensions are required in order to describe the cable as a long, thin (flexible) tube.

With this extension, the different energy regimes in which the four fundamental forces act, as well as their different dependencies on distance, can be unified in one theory. Rodriguez' model to generate jets for rotating black holes is independent of mass and angular momentum; it can be applied both to such extremely massive cosmic heavyweights as presumably exist in all spiral galaxies and to their less massive counterparts that were generated by a stellar explosion.

The researcher's computations indicate that the jets can differ significantly from each other in terms of form and energy involved: they can be extremely focused or broadly fanned out. "We still have to find out which of the solutions nature favors under which conditions," says Maria Rodriguez. There are also some cases in which no jets at all are generated.

One example here is the object at the center of our Milky Way. Its vicinity emits radio emissions, but there are no high-energy jets. In years of hard work, Reinhard Genzel and his colleagues from the Max Planck Institute for Extraterrestrial Physics observed the orbits of individual stars around the Sagittarius A* radio source at the center of the galaxy.

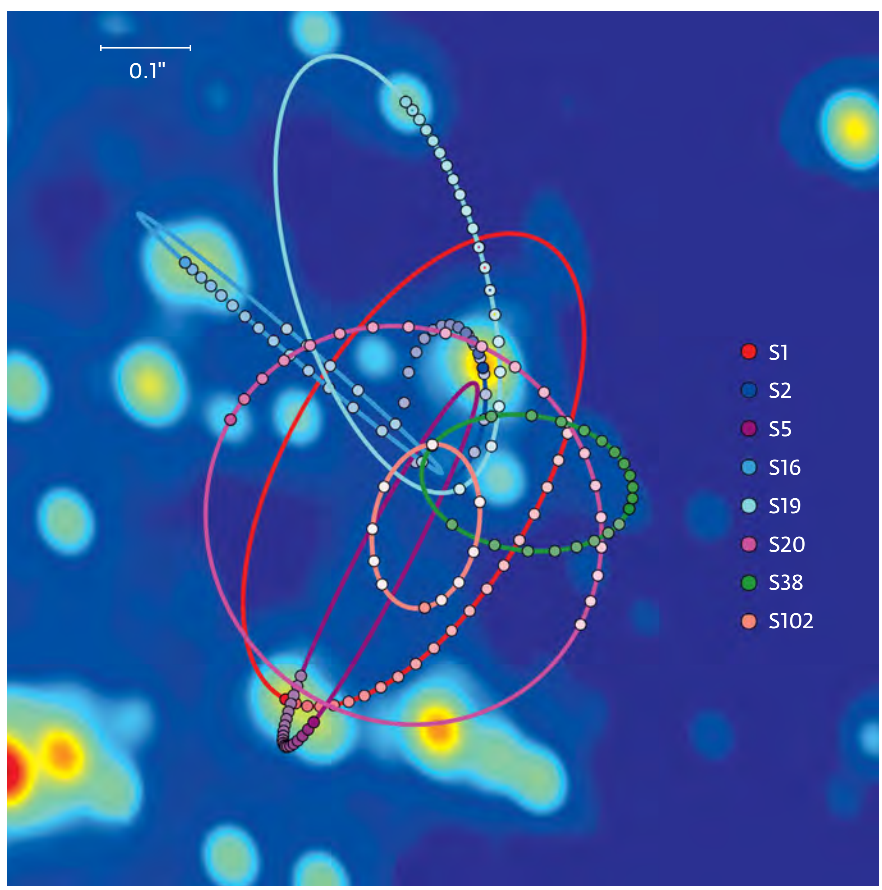
The breakthrough came in 2002, when the astronomers used the interferometers of the Very Large Telescope at the European Southern Observatory (ESO) in Chile to observe how the star S2 came to within a distance of 12 milli-arcseconds from the source of Sagittarius A*. This corresponds to a distance of just 17 light-hours. By comparison, light takes around five hours to travel from the Sun to Pluto. With the aid of earlier images, Genzel and his colleagues, among others, completely reconstructed the extremely elliptical orbit of the star S2 about the compact radio source, which has a period of 15.2 years.

Using Kepler's third law, the researchers estimated the mass of the central object to be around 3.7 million solar masses. Limited to such a narrow spatial area, it could only be a black hole. Thanks to more accurate measurements on other stellar orbits, astronomers today assume it has around 4.5 million solar masses.

But maybe black holes could make their presence felt in a completely different way. Perhaps the conventional view that says that these compact objects can be persuaded to reveal information about only very few properties, such as mass and – possibly – angular momentum and charge, is incomplete. Stephen Hawking already proposed in the mid-1970s that black holes really could emit a specific form of radiation – the Hawking radiation named after him. Theoretician Jacob Bekenstein had speculated shortly before this that the surface of the event horizon could represent a measure for the thermodynamic entropy.

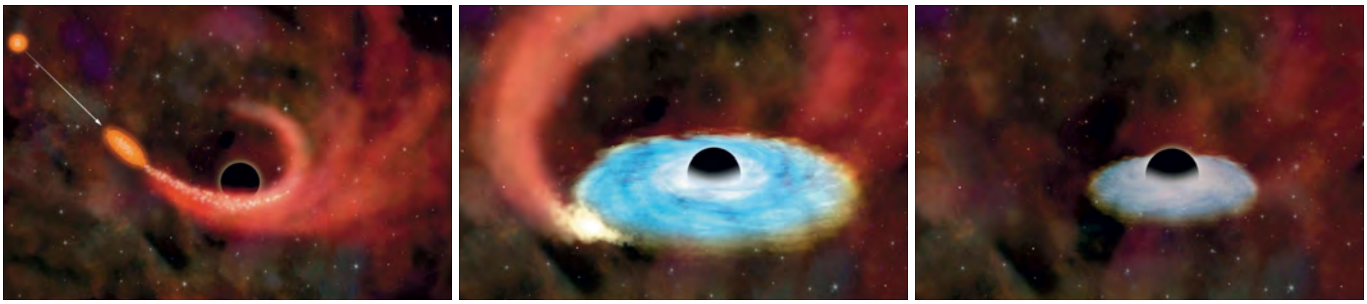
INFORMATION MAY POTENTIALLY BE PRESERVED

Entropy can be considered to be a measure of the information content of a system: the higher the entropy, the more information is contained in the system. Bekenstein and Hawking were the first to compute the entropy of a black hole, but it didn't match at all with that of the precursor star from which the hole was formed. Scientists have still not been able to fully clarify what happens with entropy and information in a black hole. Within the scope of the theory of relativity, information could be destroyed in the hole; this, however, is contradicted by the concepts of quantum physics. String theory also tackles the problem of entropy and provides



Around the center: A black hole with around 4.5 million solar masses lurks at the heart of the Milky Way. The gravity of the object forces nearby stars onto more or less elliptical orbits. Between 1995 and 2014, astronomers measured these motions very accurately using the Keck telescope in Hawaii.

Graphic: UCLA Galactic Center Group – W.M. Keck Observatory Laser Team



Drama in three acts: A star is torn apart by the tidal effect of a black hole (left). It then devours a portion of the stellar debris, heating up strongly in the process (center). This, in turn, leads to a gigantic outburst of radiation, which subsides again in time (right).

solutions for a finite entropy content. The information from the event horizon would then possibly become available to an external observer.

In this context, earlier work that Maria Rodriguez produced during her postdoc phase at the Max Planck Institute in Golm, in the research group of Director Hermann Nicolai, could also become interesting again. At that time, she developed a whole catalog of solutions for black holes in higher dimensions based on string theory. In the three-dimensional representation we are familiar with, they look like a sphere, a donut-like ring, either on its own or orbiting a sphere, similar to the ringed planet Saturn; or like two entwined rings. In the higher dimensions, all these surfaces are interconnected to give a solution.

If black holes really do emit a specific type of radiation, it will probably be extremely difficult to measure it even at some time in the future. But maybe it will soon be possible to check specific effects from Rodriguez' models for conventional black holes with the aid of observations.

A network of radio telescopes spread all over the world is currently being set up, the so-called Event Horizon Telescope. The astronomers want to use this and the Very Long Baseline Array to image the galactic center with much better resolution. In addition, they want to look more closely at the heart of the active galaxy known as M 87, which has a high-energy jet. This is thought to be the site of an extremely massive black hole with 6.6 billion solar masses. In this way, the researchers hope to find out whether jets really are formed in the ergosphere of a black hole, or in a disk of matter further out after all.

Certain effects of quantum gravitation, in contrast, should affect the gravitational wave signals from black holes. Most recent estimates have shown that the sensitivity of the LIGO detectors during the recently launched measurement campaign should be high enough to either confirm or exclude them. Gravitational wave astronomy will thus one day shed some further light on the nature of black holes. ◂

TO THE POINT

- **The gravity inside a black hole is infinitely large, and space-time has an infinitely large curvature. However, this mathematical singularity has no meaning from a physical point of view.**
- **What is crucial is the separation from the point mass below which gravity becomes so strong that nothing more can escape from it. This boundary is identified by the event horizon. This is a perfect sphere for black holes that aren't rotating and have no electric charge.**
- **But static black holes are very rare in nature. The researchers are therefore attempting to compute the behavior of rotating black holes and the physical processes in their immediate vicinity according to the laws of the general theory of relativity.**
- **Analytically, such computations have been successful only for very slowly rotating black holes. Maria Rodriguez, on the other hand, investigates objects that rotate about their own axis at almost the speed of light. She uses string theory methods for this purpose.**

GLOSSARY

LIGO: The Laser Interferometer Gravitation Wave Observatory consists of two detectors sited in the US states of Louisiana and Washington. This is where gravitational waves were first discovered on September 14, 2015. Although the installation, which is called Advanced LIGO in its present upgrade stage, is located in the US, Max Planck researchers made a significant contribution to the discovery through hardware, computer programs and models.

Riemannian space: An object from the branch of mathematics known as Riemannian geometry with special properties. For instance, the shortest connections between different points aren't necessarily straight lines, but can be curved lines. And the angular sum of triangles can be greater or less than 180 degrees.

Computer graphic: NASA/CXC/MPI for Extraterrestrial Physics

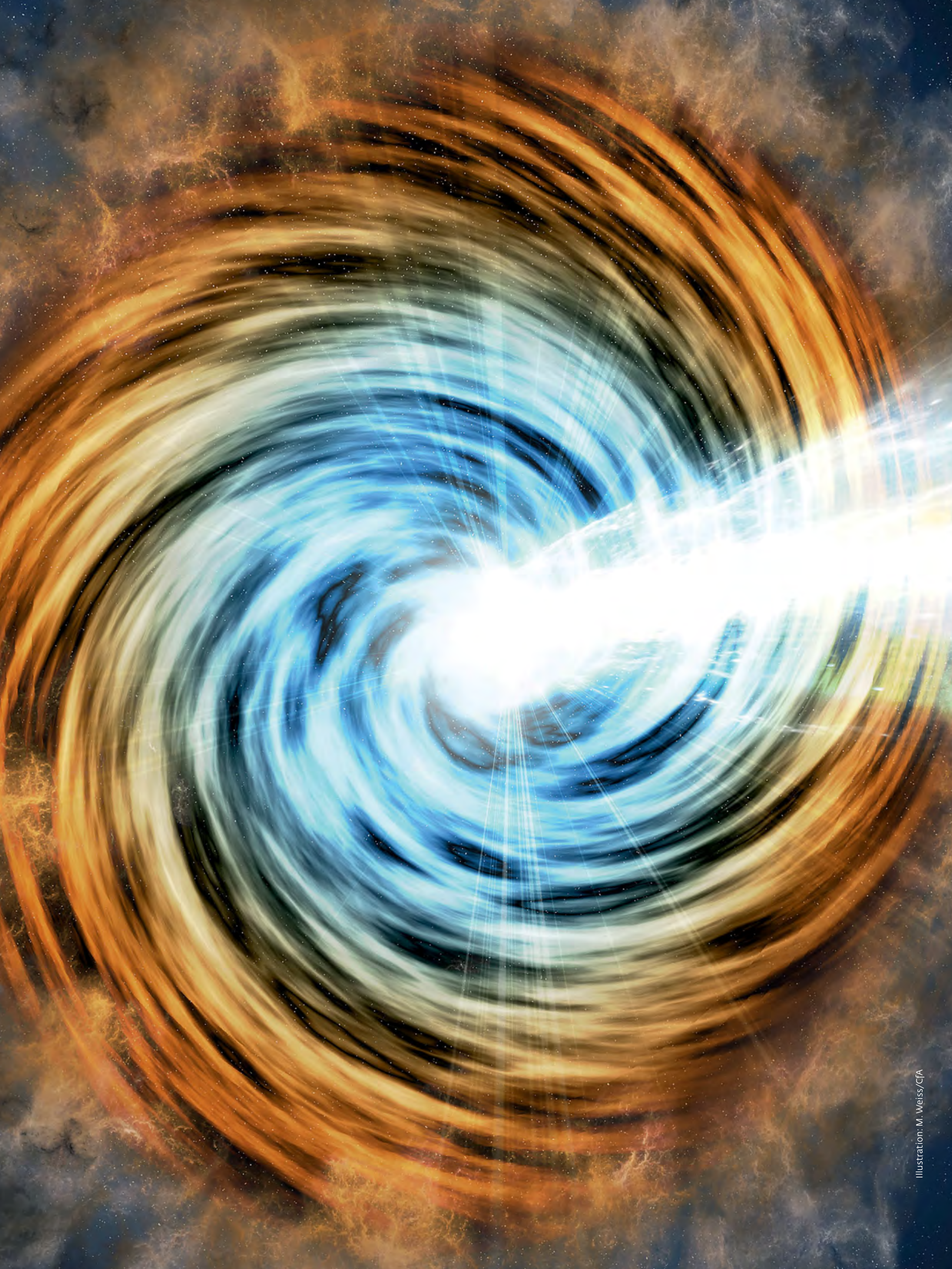


Illustration: M. Weiss/CfA

Mass monster shines brightly: The galaxy PKS 1441+25 belongs to the group known as quasars. A black hole at the center of the galaxy attracts matter, some of which is ejected outward at almost the speed of light in the form of two jets; the illustration shows one of these jets.

Cosmic Particle **Accelerator**

Black holes, pulsars, remnants of exploded stars – these celestial bodies accelerate particles to enormous energies and emit high-energy gamma radiation. The two observatories known as H.E.S.S. and MAGIC, whose construction was supervised by the **Max Planck Institutes for Nuclear Physics** in Heidelberg and **Physics** in Munich, make this extreme spectral region accessible.

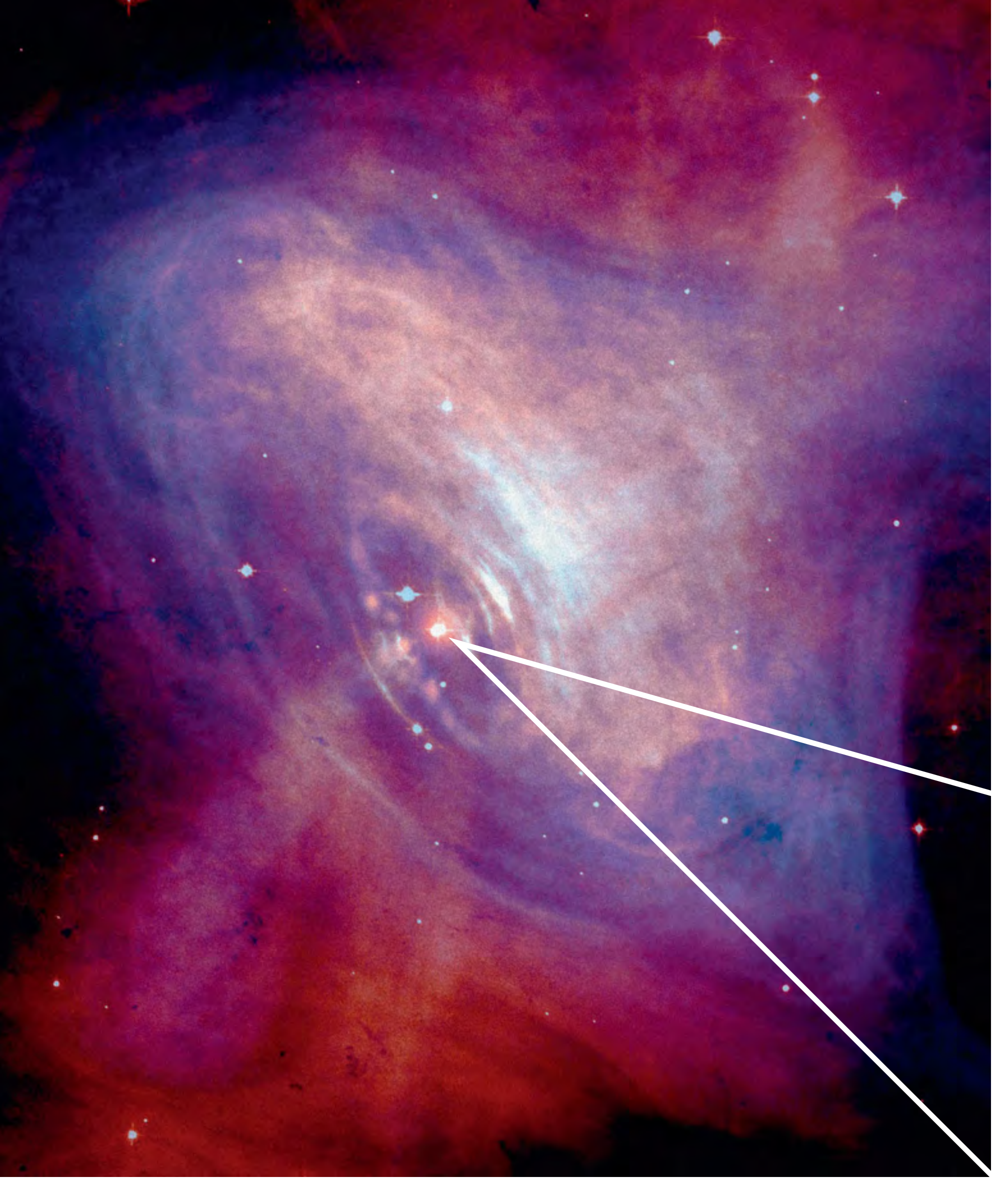
TEXT **THOMAS BÜHRKE**

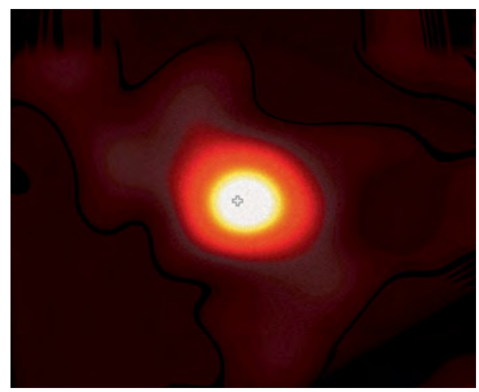
If you ask Werner Hofmann about the most recent discoveries of the H.E.S.S. observatory, he quickly starts to discuss a recently completed sky survey. "After a total of 3,000 hours of observation time, spread over ten years, we found 77 new celestial bodies that were previously unknown in this energy range," says the Director at the Max Planck Institute for Nuclear Physics in Heidelberg. He supervised the construction of the observatory, and has been honored for this many times, most recently with the Stern-Gerlach Medal of the German Physical Society (DPG).

This one sentence summarizes the difficulties that astrophysics has to overcome with respect to high-energy gamma radiation: It takes a lot of time – and the largest telescopes in the world – to observe this faint radiation. Moreover, it requires a trick, which H.E.S.S. also uses: the High Energy Stereoscopic System.

The gamma radiation can't pass through Earth's atmosphere, but it still makes itself felt on the ground. If it penetrates into the air, it gets itself into a violent exchange of blows with the electric fields of atoms. This produces new particles that continue their journey toward Earth's surface like an avalanche. Individual charged particles tear along faster than the speed of light.

This sounds surprising, but the speed of light in air is slightly lower than in a vacuum. It also means there is no violation of Einstein's law, which states that a body cannot move faster than the speed of light in a vacuum. >





At the heart of the Crab nebula: The remnant of a supernova whose light reached Earth in the year 1054 contains a pulsar (small image). Behind this object is a neutron star that rotates about its own axis 30 times per second, emitting pulsed radiation as it does so. The MAGIC telescopes recorded gamma radiation with a record-breaking energy of 1.5 trillion electron volts.

Photos: NASA/HST/ASU/J. Hester et al. X-ray: NASA/CXC/ASU/J. Hester et al. (large image); NASA/HST/ASU/J. Hester et al. X-ray: NASA/CXC/ASU/J. Hester et al. (small image)

But in the air, these particles generate a flash of light that lasts only a few billionths of a second – a "superphotic bang," as it were.

This very weak Cherenkov radiation can be observed with large telescopes on the ground. High-energy gamma astronomy thus uses the atmosphere as an enormous fluorescent screen. The Cherenkov pool of light has a diameter of 250 to 500 meters on the ground. If this pool includes a telescope, the orientation and the intensity of the flash of light can be used to determine the energy of the gamma radiation and the direction from which it comes.

The H.E.S.S. observatory is located in the highlands of Namibia and comprises four telescopes, each with 12-meter collecting mirrors and a 28-meter-diameter reflector. Its counterpart MAGIC – Major Atmospheric Gamma-Ray Imaging Cherenkov Telescopes – is located on Roque de los Muchachos, a 2,400-meter-high mountain on La Palma in the Canary Islands. It has two telescopes, each with 17-meter collecting mirrors.

TWO OBSERVATORIES DISCOVER 139 SOURCES

"MAGIC and H.E.S.S. together can observe the whole of the northern and southern hemispheres," says Masahiro Teshima, Director at the Max Planck Institute for Physics in Munich. The two observatories complement each other slightly in their abilities, as well: "Thanks to their stereoscopic view and their large mirrors, the MAGIC telescopes can detect radiation with lower energy than H.E.S.S., but H.E.S.S. is more sensitive at very high energies and has a more detailed resolution," says Teshima's colleague David Paneque, who is responsible for coordinating the scientific work of MAGIC.

Of all 178 currently known celestial bodies that emit high-energy gamma radiation, 105 were discovered with H.E.S.S. alone, and 34 with MAGIC – a success that put H.E.S.S. among the world's top 10 observatories in 2009, together with the Hubble Space Telescope.

The gamma radiation sources are evidence of the most violent events in the universe, for instance of stellar explosions and their consequences. When a star has consumed its fuel at the end of its life, energy production comes to a halt. The center collapses within fractions of a second under the effect of gravity. The outer regions, in contrast, explode, shooting out into space and shining brightly. A supernova flares up.

If the collapsing core has less than three solar masses, a neutron star forms

» In a neutron star, matter is so strongly compressed that one teaspoon of it on Earth would weigh as much as one million long-distance trains.

– an extremely compact, rapidly rotating sphere with a diameter of 20 kilometers. Matter is so strongly compressed in such an object that one teaspoon of it on Earth would weigh as much as one million long-distance trains.

The magnetic field of the former star is also compressed in this collapse. This dipole field resembles our Earth's field with north and south poles, but is several billion times stronger and rotates several million times faster. According to the current way of thinking, electrically charged particles break loose from the star and are accelerated along the axis of the magnetic field into space at almost the speed of light.

This process generates radiation in a complex manner, predominantly in the direction of motion – like a car headlight. The swarm of particles thus generates two light cones that point into space from both the north and south poles of the neutron star.

In many cases, the axis of the magnetic field is inclined at an angle to the axis of rotation. The two light cones thus sweep through space like the beam of light from a lighthouse. If they happen to sweep across Earth, the telescopes detect radiation pulses with the rotational frequency of the celestial body. Astrophysicists call this a pulsar. These objects are deemed to be cosmic laboratories in which physical processes and theories can be tested under extreme conditions.

In 1989, astrophysicists discovered a celestial body in the high-energy gamma region for the first time. It was the Crab nebula – the remnant of a supernova explosion whose flare-up was first discovered in April 1054 by a monk in Flanders. At its center is a pulsar that rotates about its own axis 30 times per second. It can now be observed in all spectral regions, from radio waves to visible light to high-energy gamma radiation. While it is thought to be the best-investigated supernova remnant, it still throws up new mysteries time and time again.

THE MAGNETIC FIELD PLAYS THE KEY ROLE

Thanks to MAGIC, the researchers were recently able to register pulsed gamma radiation from this object with a record-breaking energy of 1.5 tera-electron volts (TeV), or 1.5 trillion electron volts. This is the most energetic pulsed radiation ever measured in a star. For comparison, visible light has an energy of two to three electron volts.

To obtain these results, which were published in early 2016, the MAGIC team had to evaluate 320 hours of observations from the period from October 2007 to April 2014. "The only thing that is clear is that the very strong magnetic field of the Crab nebula plays a key role," says Razmik Mirzoyan, spokesperson of the MAGIC collaboration and project leader at the Max Planck Institute for Physics in Munich.

In order to unravel how this cosmic accelerator works, astrophysicists and particle physicists have to work together. They conclude that electrons and their antiparticles – called positrons – are accelerated to almost the speed of light in the magnetic field and finally annihilate, but this process can likely explain only gamma radiation with energies of up to a few billion electron volts (GeV). A different mechanism must be responsible for most of the recently observed gamma pulses.

The researchers currently assume that high-energy, charged particles form a "reactive mixture" with photons of UV and X-ray radiation around 1,500 kilometers above the surface of the pulsar in that the particles transfer their energy to the photons and upgrade them to high-energy gamma quanta. This process is called the inverse Compton effect.

The gamma radiation that H.E.S.S. and MAGIC registered is therefore a secondary effect. The actual cause are particles that are accelerated under extreme cosmic conditions. Since no conversion process is perfect, the scientists think that the primary particles have more energy than the gamma radiation they produce.

Things in the surrounding explosion cloud, which expands at a speed of 1,500 kilometers per second, are very turbulent – and it is an efficient accelerator, too. This hot gaseous cloud is permeated by magnetic fields that accompany it as it moves away from the star. A game of nuclear table tennis takes place: electrically charged particles, mainly hydrogen nuclei (protons), are pushed to and fro between magnetic field fronts and continuously gain

» Computer simulations indicate that the ultrafast protons can exert a pressure and disperse interstellar clouds.

energy in the process – until they are so fast that they can escape from this ping pong. This process only works if the magnetic fields are in motion.

IN CAPTIVITY FOR SEVERAL CENTURIES

"Until recently, we expected that the particles remain trapped in the nebula for millennia before they can escape," explains Jim Hinton, who heads the Non-Thermal Astrophysics Department at the Max Planck Institute for Nuclear Physics in Heidelberg. "But according to our measurements, they escape after only several centuries."

As current models suggest, these findings are probably also relevant for the evolution of the Milky Way. The ultrafast particles break away from their accelerators at some stage and form a "gas" that is spread throughout the galaxy. "Computer simulations indicate that the ultrafast protons can exert pressure and disperse interstellar clouds," explains Hinton. This would mean that the cosmic particles suppress star formation in a galaxy. These studies are still in their infancy, but they show that the effect these particles have on the evolution of the universe is still far from being understood.

The protons and electrons whiz around all over the Milky Way and, in the process, possibly also impact on Earth. Austrian physicist Victor Franz Hess (1883 to 1964) discovered this cosmic radiation more than 100 years ago on balloon flights. The name of the telescope array in Namibia also commemorates him.

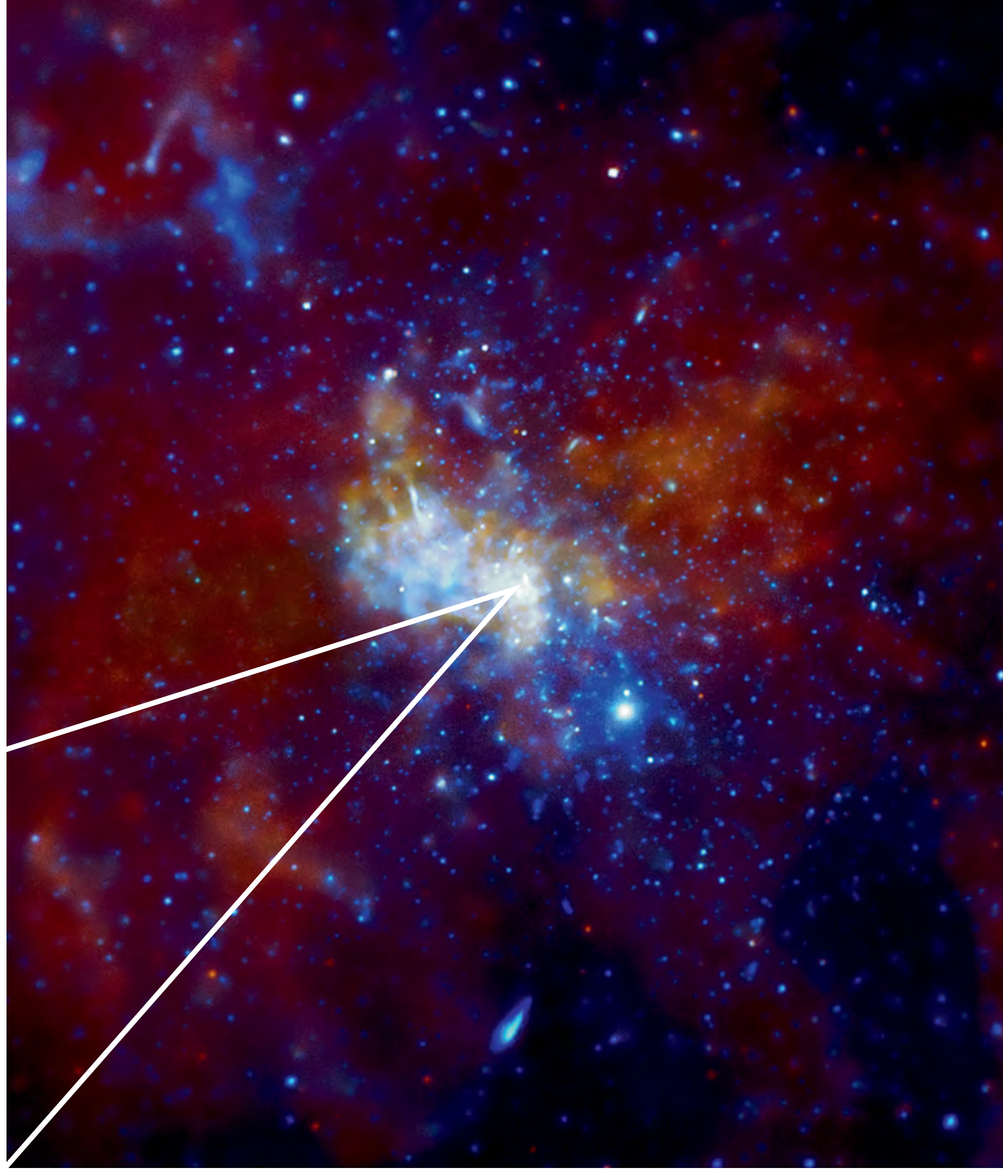
Although the currently known celestial bodies produce cosmic radiation with energies of up to 100 trillion electron volts (100 TeV), particles with much higher energies are measured. Where do they come from?

H.E.S.S. provided part of the answer at the start of 2016. An analysis of measurement data from the years 2004 to 2013 demonstrated that the gamma radiation coming from the center of our Milky Way is so energetic that an accelerator there must be speeding up protons to up to 1,000 trillion electron volts (1 peta-electron volt). The researchers therefore call it a pevatron (MaxPlanckResearch 2/2016, page 42).

Current findings indicate that this radiation is caused by a gigantic black hole because, over the past 20 years, large numbers of astronomical observa-

Photo: Axel Griesch

Good view from here: Razmik Mirzoyan (left) and David Paneque from the Max Planck Institute for Physics observe the universe with the two MAGIC telescopes on La Palma. The picture shows the researchers standing on a construction model for a new gamma radiation telescope that is also set to be built on La Palma.



Cosmic accelerator: A source of intense radiation sits at the center of the Milky Way. This artist's impression (small image) shows processes that contribute to the generation of high-energy gamma radiation. Protons (blue spheres), which are accelerated by the black hole Sagittarius A* at the center, interact with clouds of molecules in the vicinity. This produces pions, among other things, which decay almost immediately into gamma radiation photons (yellow waves).

Photo: X-ray: NASA/CXC/MIT/F. Baganoff et al. (large image); graphic: Dr. Mark A. Garlick/H.E.S.S. Collaboration (small image)

tions have shown with increasing accuracy that our Milky Way rotates about a black hole concealing a mass of around 4.5 million Suns. This object, called Sagittarius A*, is surrounded by a hot disk of gas from which it draws in and then swallows matter.

The H.E.S.S. researchers conclude from the data that the cosmic accelerator in the galactic center has been in continuous operation for tens of thousands of years. However, the exact details of how and where the particles are brought up to speed are not clear. It takes place either in the immediate vicinity of the black hole or in the surrounding disk, where some of the matter that falls toward the mass monster is ejected again and accelerated in magnetic fields.

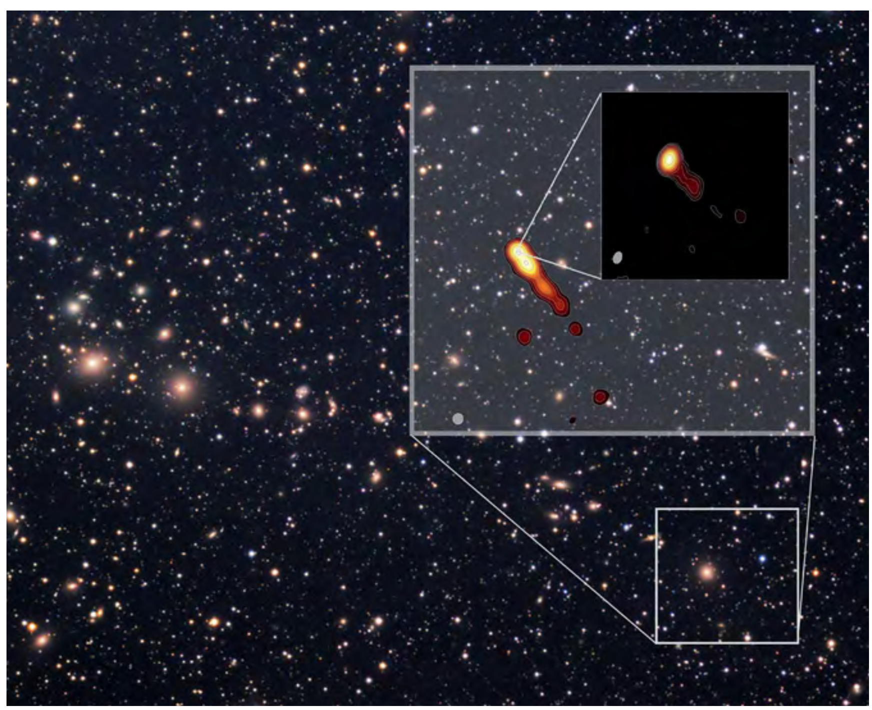
The mystery of the most energetic particles of cosmic radiation thus remains unsolved. Particles with up to 100,000 PeV have been detected by the international Pierre Auger Observatory in Argentina. Their origin is completely unclear. The main candidates are thought to be centers of galaxies that accommodate black holes but are much more massive and considerably more active than the center of our Milky Way.

GRAVITATIONAL TRAPS COLLECT SCORES OF GAS AND DUST

Astronomers know of types of galaxies that could be responsible: quasars, radio galaxies and blazars. The supermassive black holes at their centers can be as heavy as several billion solar masses and collect vast amounts of gas and dust – sometimes even entire stars – from their surroundings. This releases significantly more radiation – including high-energy gamma radiation – than is emitted by all the stars in the surrounding galaxy.

However, the large distances involved make it very difficult to detect it. Of the 13 most distant objects currently known, eight were discovered by MAGIC, two by H.E.S.S., one by the two of them together and two further ones with VERITAS, the **V**ery **E**nergetic **R**adiation **I**maging **T**elescope **A**rray **S**ystem with four 12-meter telescopes located in the US state of Arizona. The objects emitted the radiation registered when the universe was at most only two thirds of its present size.

MAGIC currently holds the distance record with its detection of the two active galaxies PKS 1441+25 and B0218+357. "We were able to track down these objects because we have used various technical measures to increase the sensitivity of MAGIC tenfold for low-energy gamma radiation since it was commissioned," says Max Planck researcher David Paneque. "This shortened the observation time needed for



Top Specialist for high energies: Werner Hofmann, Director at the Max Planck Institute for Nuclear Physics in Heidelberg, supervised the construction of the H.E.S.S. observatory in Namibia.

Bottom Intense source: The galaxy IC 310, which is 260 million light-years away, experiences violent outbursts of radiation. These are presumably connected to the magnetic field that surrounds a central, supermassive black hole. The inset shows the inner region of IC 310 in high resolution in the radio wave region.

very distant objects to one hundredth of the original value."

PKS 1441+25 is an example of a so-called blazar, a celestial body that often exhibits very powerful radiation bursts. The Fermi space telescope detected one of these eruptions in April 2015. A global alarm was immediately triggered at selected observatories, and when MAGIC directed its sights toward this object, the gamma radiation was up to 100 times more powerful than normal. This outburst was also observed by other telescopes, for example in the visible and X-ray ranges (MaxPlanckResearch 1/2016, page 44).

LIKE LOOKING INTO A BRIGHT HEADLIGHT

This is where the special characteristic of blazars comes into play. The central supermassive black hole accretes matter from the surrounding gaseous disk, and in doing so, diverts some of it – probably as a result of magnetic fields – into two beams or jets that shoot out into space in opposite directions at right angles to the disk. In the case of a blazar, one of the two jets is coincidentally directed toward Earth, meaning that the astronomers and their instruments look into it as if into a bright headlight.

"We believe that the outburst took place far away from the black hole in a compact region inside this jet," says David Paneque. Compact here means roughly as big as our planetary system, but not filling the whole diameter of the jet. "The mixture of particles and magnetic fields gives rise to turbulence and shocks in which the particles experience strong acceleration and thus produce radiation," says the researcher.

A further highlight is the observation of the radio galaxy IC 310, whose separation of 260 million light-years puts it more in the galactic neighborhood. On November 13, 2012, MAGIC recorded radiation outbursts of previously unknown intensity.

What was surprising about this outburst was that it lasted less than five

» Exactly what happens in the immediate vicinity of the black holes and further out in the jets is still nowhere near final clarification.

minutes. This allows conclusions to be drawn about the size of the region that flared up, because no object can illuminate faster than light takes to travel across it. The region from which the gamma radiation originated must therefore be significantly smaller than the black hole with a mass of 300 million solar masses whose diameter measures around 23 light-minutes.

"We assume that the black hole rotates rapidly and is surrounded by a magnetic field," says Paneque. As a result, strong electric fields occur in the polar regions, which accelerate electrons and their antiparticles (positrons) to almost the speed of light. These then generate the gamma radiation when they interact with their surroundings.

This can be imagined to be something like flashes of lightning that discharge every few minutes. The lightning in space releases its energy over a region the size of our planetary system. All of this takes place very close to the black hole. "With these observations, we are trying to look directly into the machinery at the center of the galaxy, as it were," says Razmik Mirzoyan.

LOCATIONS ON LA PALMA AND IN THE CHILEAN ANDES

Exactly what happens in the immediate vicinity of the black holes and further out in the jets is still nowhere near final clarification. The researchers are also puzzling over the question of whether active galaxies produce those cosmic radiation particles detected with the Pierre Auger Observatory, that plunge into the terrestrial atmosphere with extreme energies.

The successes of H.E.S.S. and MAGIC have led to the decision to create an international successor project: the Cherenkov Telescope Array (CTA). This observatory will be established at two locations: in the Chilean Andes and on La Palma, the current location of MAGIC. With 19 telescopes on La Palma and 99 in Chile, the researchers again have the whole sky in their sights.

"If everything goes according to plan, we can start with the construction as early as 2017," says Masahiro Teshima. And his colleague Werner Hofmann from Heidelberg adds: "With the CTA, the observation times needed will be a hundred times shorter than those of H.E.S.S. or MAGIC." So things are looking good for astroparticle physics. ◂

TO THE POINT

- **Astronomers currently know of 178 celestial bodies that emit high-energy gamma radiation. It can be observed indirectly from the ground with telescopes such as H.E.S.S. and MAGIC.**
- **The Crab nebula, a supernova remnant, is among the best-investigated objects. Researchers registered pulsed gamma radiation with a record-breaking energy of 1.5 trillion electron volts from the center of the pulsar.**
- **At the heart of the Milky Way sits a cosmic accelerator that accelerates protons to energies of up to 1,000 trillion electron volts (1 peta-electron volt).**
- **The Pierre Auger Observatory in Argentina has even detected particles of up to 100,000 PeV from the cosmos. Their origin is completely unclear. The main candidates are thought to be centers of galaxies with black holes that are much more massive and considerably more active than that in the Milky Way.**

GLOSSARY

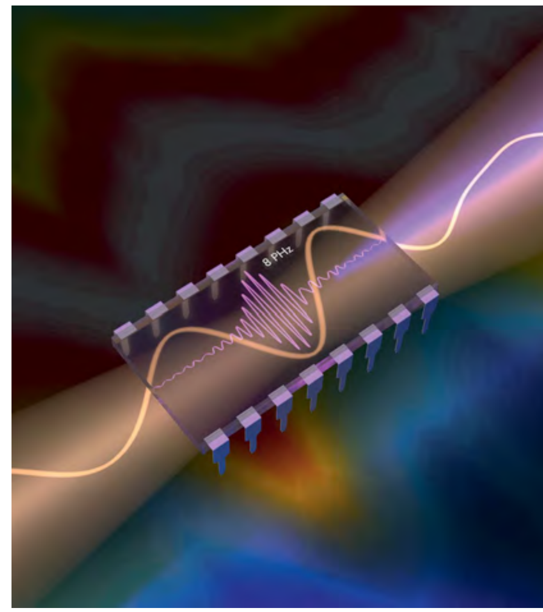
Electron volt: A unit of energy, abbreviated eV. If an electron is accelerated in an electric field, its kinetic energy changes by one electron volt when the accelerating voltage is one volt. In the largest accelerator on Earth, the LHC, protons are accelerated to approximately 7 TeV (7×10^{12} eV). The most energetic particles in the cosmic radiation have energies of more than 10^{20} eV. The energy of radiation can also be stated in the unit eV.

Jets: Bundled beams of matter in which particles fly into space in a specific direction at almost the speed of light. They are produced when a black hole accretes gas from a rotating disk. As this happens, only a portion of the gas in the disk plunges into the gravitational trap – the other portion streams away at right angles to the plane of rotation in the form of jets.

Electronics at Record Speed

Ultrashort laser flashes generate current a million times faster than in modern microprocessors

Electronic components could be made to run much faster by accelerating their electrons with light. Using extremely short laser pulses, researchers at the Max Planck Institute of Quantum Optics in Garching recently made electrons oscillate at petahertz frequencies – around 1,000 times faster than the clock speeds of modern microprocessors. The current produced in the process doesn't fit the classical model of charge transport. As a quantum current, it doesn't simply flow from the negative pole to the positive pole of a battery. Instead, the electrons oscillate extremely rapidly in the quantum realm. This state can't be achieved with ordinary current sources, as atoms, which also vibrate, cause the electrons to oscillate out of sync. Ultrashort laser flashes, on the other hand, stimulate the electrons so quickly that the relatively slow atoms no longer cause interference. Not only is the current generated a million times faster; the conductivity of the material increases by a factor of ten quintillion – that's one followed by 19 zeros. The researchers also discovered a way to detect the quantum current: the electrons emit light at their oscillation frequencies, which is easier to measure than the current itself. (www.mpg.de/10805872)



Laser pulses (large sine wave) generate electric currents at petahertz frequencies (small sine waves in the electronic component sketched here). Currents are revealed by the UV radiation emitted.

My Contribution to Arctic Sea Ice Melt

Measurements reveal the correlation between CO_2 emissions and summer ice shrinkage

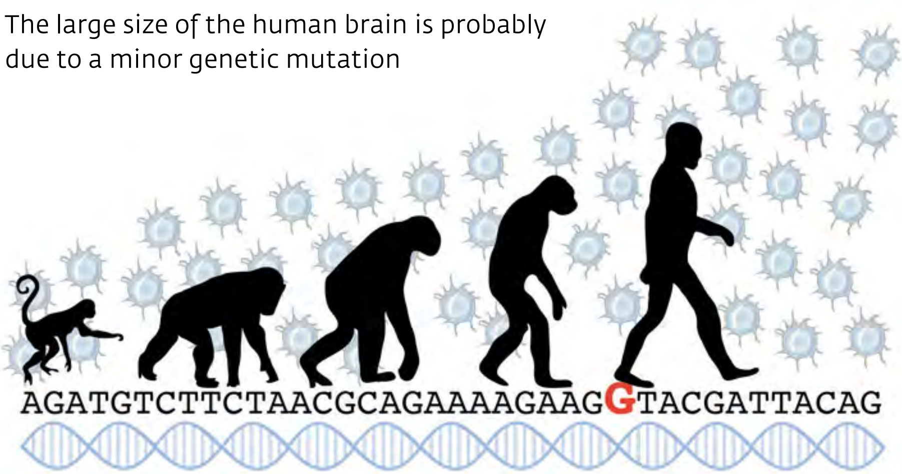
Every ton of carbon dioxide released by humans on the planet causes the summer sea ice in the Arctic to shrink by three square meters. Dirk Notz, a scientist at the Max Planck Institute for Meteorology, and Julienne Stroeve, a researcher at the US National Snow and Ice Data Center, came to this conclusion by analyzing measurements. They also discovered that, because they underestimate the increase in thermal radiation in the Arctic, many climate models predict a slower rate of ice melting than is observed in real life. The data also clearly shows that limiting global warming to two degrees Celsius, as called for by the most recent UN climate conventions, won't be enough to prevent summer ice melt in the Arctic Sea. (www.mpg.de/10817029)

Scientists, including researchers from the Max Planck Institute for Meteorology, taking samples of Artic Sea ice near Spitzbergen for later analysis.

Graphic: MPI of Quantum Optics (top); photo: Dirk Notz (bottom)

Scrambled Letters with Consequences

The large size of the human brain is probably due to a minor genetic mutation



The swap of a single letter (red) in the code of the ARHGAP11B gene resulted in modern humans producing more stem cells in the brain than apes.

About one and a half million years ago, a tiny but fateful misspelling occurred in the three-billion-letter-long text of the human genome: a C was replaced by a G in the ARHGAP11B gene. This gene causes stem cells to multiply and form new nerve cells. ARHGAP11B was created by a partial doubling of a predecessor gene after the evolutionary lines of humans and apes separated. It occurs only in humans and our closest, now extinct, relatives, the Denisova hominids and the Neanderthals, but not in chimpanzees. After the mutation, the ARHGAP11B gene was able to develop its full potential. According to researchers at the Max Planck Institute of Molecular Cell Biology and Genetics in Dresden, the point mutation caused more stem cells to form in the cerebrum of modern humans. Consequently, our brains grew in size, endowing us with the intellectual skills that characterize humans, such as language and thought. (www.mpg.de/10851125)

A Nose for Oxygen

Mice have specialized neurons in the nasal mucosa that let them detect the oxygen content of the air

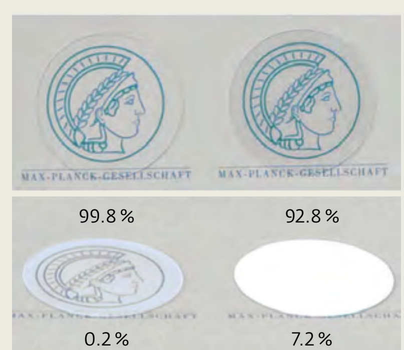
The mouse's keen sense of smell is hardwired in its genome: more than a thousand genes are dedicated to synthesizing receptor molecules for the olfactory sense, including one for a gas that we humans wouldn't normally think of as having an odor: oxygen. According to scientists at the Max Planck Research Unit for Neurogenetics in Frankfurt, mice can sniff out the oxygen content of the air with the help of type B neurons in their nasal mucosa. These cells are activated in response to a decrease – however slight – in the oxygen concentration of the air. The rodents can therefore smell a decrease of an odor – an ability that has yet to be found in any other animal. The key to this ability lies in the Gucy1b2 and Trpc2 genes, which contain information for molecules involved in signaling pathways in type B cells. However, it is still unknown exactly which receptor detects the oxygen content. Nor do the researchers know whether type B cells that respond to low oxygen levels also occur in humans. (www.mpg.de/10843354)

Graphic: MPI of Molecular Cell Biology and Genetics (top), Zhaolu Diao (bottom)

Superlative Coating

A surface with two-micrometer-high nanocolumns transmits almost all of the incident light

Antireflective coatings will soon be a lot more effective. Researchers at the Max Planck Institute for Intelligent Systems in Stuttgart have found a way to produce, on glass surfaces, nanostructures that reflect almost none – and transmit almost all – of the incident light. They have developed a method to produce conical columns measuring around two micrometers high on surfaces. Along surfaces coated with such columns, the refractive index changes continuously. Most light in the visible and shortwave spectrum is therefore able to penetrate the surface over a relatively wide range of angles of incidence. Conventional antireflective coatings and shorter nanoscale columns are antireflective only within a narrow range of the light spectrum and work only at very limited angles of incidence. The new antireflective coating could find applications in high-power lasers, cameras and microscopes, as well as in touchscreens and solar modules. (www.mpg.de/10797830)



A glass plate on which nanocolumns have been etched (illustrations on the left) reflects just 0.2 percent of light falling on it at an angle of 30 degrees and is transparent to the remaining 99.8 percent. At the same angle of incidence, a plate without the surface nanostructure (illustrations on the right) transmits only 92.8 percent of light, reflecting 7.2 percent.

Guided by Light

Microswimmers can be precisely guided to targets

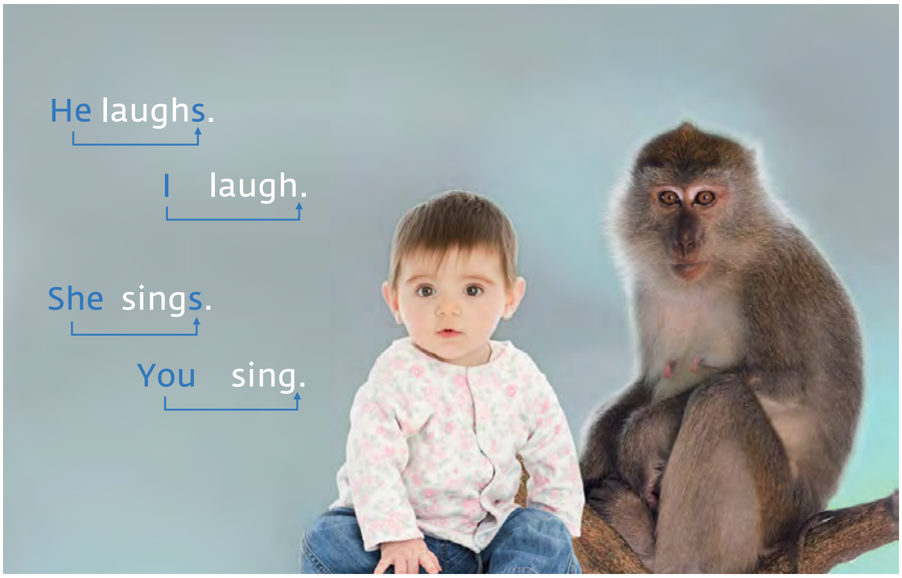
Tiny swimming objects can now mimic an ability that many microorganisms possess: in water containing a dissolved organic substance, they are able to move toward a light source or away from it, as required. To endow microswimmers with this ability, known as phototaxis, researchers at the Max Planck Institute for Intelligent Systems in Stuttgart and the University of Stuttgart use glass microbeads coated with carbon on one side. Upon exposure to light, the carbon layer and the liquid surrounding it warm up. As a result, the water and organic substance partially separate. This gives rise to a gradient in the solute concentration between the uncoated side of the bead and the carbon-coated side. To compensate for the concentration differential, water flows from one side of the microswimmer to the other, propelling it away from the light source. This orientation mechanism makes it possible to use a light source to guide microswimmers through liquids. (www.mpg.de/10756646)

Traveling toward the darkness: Glass beads coated on one side with carbon navigate autonomously away from a light source.

Monkeys with a Knack for Language

Macaques process complex sequences of syllables in a manner similar to babies

Even babies have a sense of grammar: three-month-old infants already recognize the rules for combining syllables and notice when a rule is violated. Scientists at the Max Planck Institute for Human Cognitive and Brain Sciences in Leipzig have now discovered that monkeys also possess at least the rudiments of this ability. The researchers measured electrical brain activity on the scalp of macaques while the animals listened to meaningless but rule-compliant strings of syllables. They discovered that the electrical activity pattern of the animals' brain is similar to that of a three-month-old baby. They could also tell from the macaques' brain patterns that the animals notice when a syllable string is incorrect. This ability must therefore have arisen before the human evolutionary line split off from that of other primates. However, even humans lose this ability as adults: they no longer recognize language patterns by merely listening, like babies or macaques, and have to actively search for the rules. (www.mpg.de/10821435, only in German)



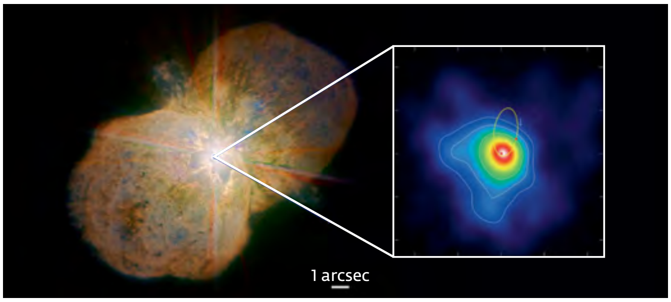
In many languages, syllables follow specific rules. In English, for example, the initial syllables "he" and "she" are followed – at variable distances – by an "s", whereas "I" and "you" aren't. Macaques and three-month-old babies recognize these rules, though the monkeys learn them more slowly than humans.

Graphic: Celia Lozano/MPI for Intelligent Systems/University of Stuttgart (top), photo: MPI for Human Cognitive and Brain Sciences (bottom)

The Turbulent Heart of Eta Carinae

Detailed images of the binary star system show the collision zone of the stellar wind

Eta Carinae is a massive and very bright binary star system. The heavier partner is one of the biggest and brightest stars in the sky, weighing in at around 100 solar masses. A team headed by Gerd Weigelt from the Max Planck Institute for Radio Astronomy in Bonn has studied Eta Carinae with the help of near-infrared interferometry for the first time. They obtained images of the area between the two stars in which the stellar winds from each star crash into each other at speeds of more than ten million kilometers an hour. Within the collision zone, the temperature rises to many tens of millions of degrees – hot enough to generate X-rays. Until now, it wasn't possible to spatially resolve this central region. The astronomers used a new image processing technique, which they applied to images taken by the AMBER instrument of the European Southern Observatory's Very Large Telescope Interferometer (VLTI). (www.mpg.de/10794673)



Interstellar storm: The left image shows the Homunculus Nebula around the massive binary star system Eta Carinae. On the right is a high-definition image of the wind collision zone in the central area of the system. This area is around 100 times larger than the diameter of each of the two stars. The yellow ellipse shows the orbit of the binary star system. The two red dots indicate the positions of the two stars at the time of the observation.

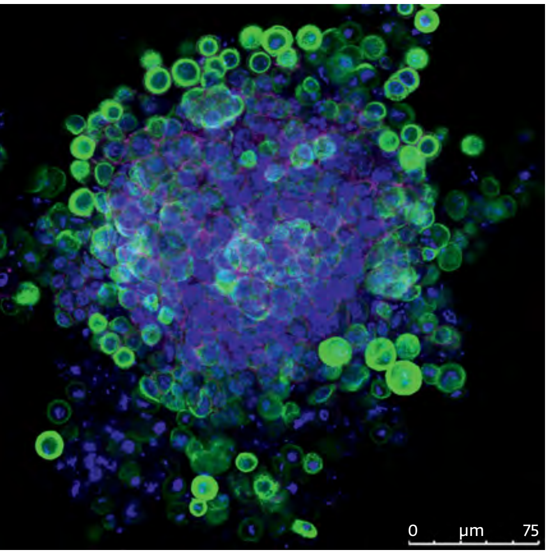
Photos: ESO (top left) and Gerd Weigelt/MPIfR (top right); MPI for Biology of Ageing (bottom)

Skin Stem Cells in a Test Tube

New method could reduce animal research

Wounds have to be healed; lost hairs have to be replaced. To achieve this, the skin uses stem cells in the hair follicles. If it were possible to successfully cultivate such stem cells in the lab, one of the benefits would be to make a lot of animal research superfluous. Until now, scientists searching for the causes of skin cancer have had to conduct research on mice. Scientists at the Max Planck Institute for Biology of Ageing in Cologne have now succeeded in cultivating mouse skin stem cells in the lab. Supplied with growth-promoting chemical messengers, skin stem cells survive for long periods in a gel consisting of natural skin proteins. In addition, the researchers found that the method can also be used to cause mature cells to revert to the stem-cell state. In the future, researchers could carry out experiments with such stem cells instead of on living skin, and even use them to test the effects of new cancer drugs. The Cologne-based scientists now hope to adapt their technique to human cells.

(www.mpg.de/10866807)



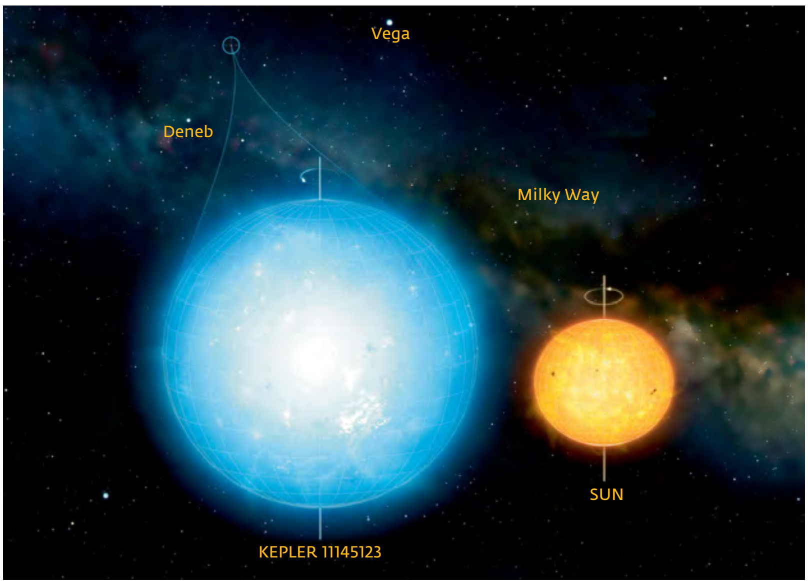
Hair follicle stem cells in cell culture under the microscope (blue: cell nucleus; green: keratin; red: actin).

Pushing the Boundaries of Microscopy

It is now possible to observe individual proteins at work in cells. To achieve this, a team of researchers headed by Stefan Hell, Director at the Max Planck Institute for Biophysical Chemistry in Göttingen, have developed the MINFLUX fluorescence microscope, which can resolve two fluorescent proteins even if they are separated by only a few nanometers – the limit of what is possible in living cells. The team achieved this feat by cleverly combining two Nobel prizewinning methods: they identify individual fluorescent molecules by randomly switching the molecules on and off, and then determine their precise positions by stimulating them with a doughnut-shaped laser beam. The researchers exploit the fact that they know the precise intensity profile of the laser beam. The whole process takes place so rapidly that it is even possible to follow the path of a protein through a cell. And the resolution is determined only by the size of the fluorescent molecules.
(www.mpg.de/10878921)

A Well-Rounded Star

Researchers measure the shape of Kepler 11145123 with unprecedented accuracy



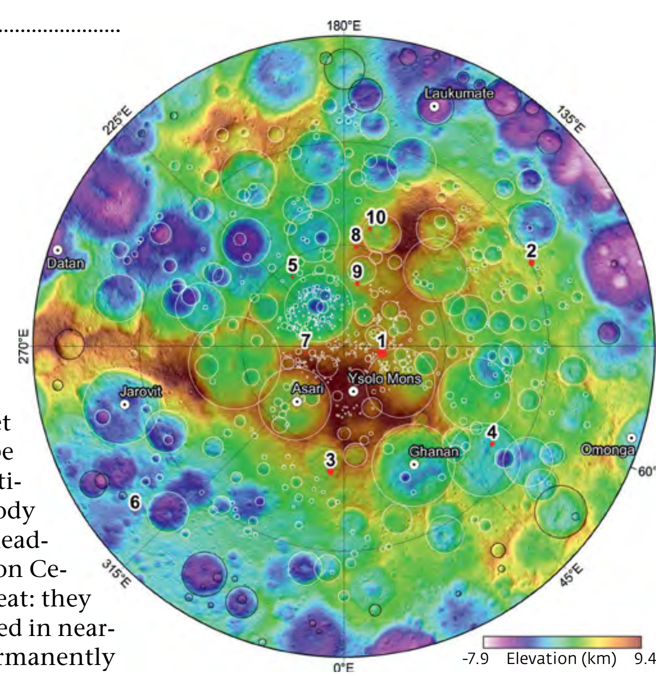
The star Kepler 11145123 is the most perfectly round natural celestial body that has ever been measured. The star's oscillations show that the difference between the equatorial radius and the polar radius is just three kilometers, making this star much rounder than our own Sun.

Stars aren't perfect spheres. As they spin on their axis, centrifugal force tends to flatten them somewhat. A team headed by Laurent Gizon from the Max Planck Institute for Solar System Research and the University of Göttingen have now measured the flattening of a slowly rotating star with unprecedented accuracy. They found a difference of just three kilometers between the equatorial radius and the polar radius of Kepler 11145123, an object located 5,000 light-years from Earth. This difference is astonishingly small in relation to the star's mean radius of 1.5 million kilometers. In other words, the gas ball is extremely round. For their measurements, the astronomers exploited the fact that the star oscillates. They compared the frequencies of oscillations that are more pronounced at the equator with those that dominate at higher latitudes. From this, they calculated the difference between two measurements: the distance from the center of the star to the pole and the distance from the center to the equator. (www.mpg.de/10827169)

Water Ice in the Eternal Polar Night

The cameras of the Dawn space probe are surveying the northern polar region of the dwarf planet Ceres

The US space probe Dawn has been orbiting the dwarf planet Ceres between Mars and Jupiter since March 2015. The probe has pointed its on-board cameras from the Max Planck Institute for Solar System Research in Göttingen at the celestial body and has now almost completely mapped its surface. A team headed by Göttingen-based scientists recently published a report on Ceres' high north. The two framing cameras achieved a special feat: they were able to photograph deposits of water ice in areas shrouded in nearly eternal darkness. Among 634 identified craters with permanently dark areas, the researchers found 10 craters on the images with surprisingly bright areas in their interior. In one relatively young crater measuring 3.8 kilometers across, the bright deposits extended beyond the permanently dark zone into a region that is sometimes exposed to direct sunlight. (www.mpg.de/10861571)



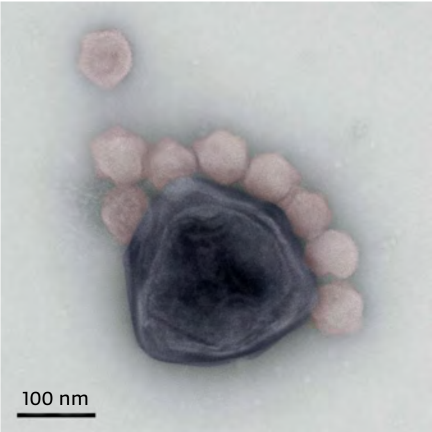
A view of the north pole: The colors show the elevation relationships on Ceres. The numbers indicate ten craters in which the framing cameras from the Max Planck Institute for Solar System Research in Göttingen detected water.

Photos and graphic: Mark A. Garlick (top); Nature Astronomy (bottom)

The Enemy of My Enemy Is My Friend

A single-cell organism protects itself from viruses with viruses

In humans, a viral infection is usually bad news. For a single-cell marine organism, however, it can mean salvation – when a parasite becomes a symbiotic partner. According to scientists at the Max Planck Institute for Medical Research in Heidelberg, however, the partnership doesn't benefit the cells that are infected first. They must die so that others may live. For the single-cell organism *Cafeteria roenbergensis*, a giant virus called CroV poses a mortal threat. After attaching itself to the cell surface, the virus causes the host cell to churn out giant viruses until it bursts. However, if a cell has previously been infected with the mavirus, it releases particles of both virus types. These maviruses save other single-cell organisms: if they reach new host cells at the same time as the giant viruses, they prevent the giant viruses from multiplying. A single-cell organism that is simultaneously infected by both viruses releases only mavirus particles but no CroV particles. Uninfected organisms are therefore protected from infection by giant viruses. The researchers are now looking for other single-cell organisms that use such unusual defense mechanisms.
(www.mpg.de/10851301)



Close relationship: Particles of the giant virus CroV (dark blue) and the mavirus (pink).

Looking Out for Others Means Longer Life

Elderly people who help and support others live longer. That is the finding of a study in which the Max Planck Institute for Human Development in Berlin participated. An international team compared survival data of more than 500 people between the ages of 70 and 103. Half the grandparents who cared for their grandchildren or actively assisted their children were still alive ten years after the initial survey. Among those who weren't actively dedicated to their offspring, by contrast, around half died within five years. The researchers also found that childless elderly people who care for friends or neighbors also benefit from the effect. However, Ralph Hertwig, Director at the Max Planck Institute for Human Development, doesn't believe that caring for others is a recipe for longevity. "Positive effects are likely only if the degree of commitment is moderate. Beyond that, it could lead to stress and have a negative impact."
(www.mpg.de/10873883)

The Fastest Fliers in the Animal Kingdom

The Brazilian free-tailed bat isn't just a skillful aviator, it also holds the current speed record

The flight characteristics of birds are unsurpassed and still serve as inspiration for aircraft engineers. Birds of the aptly named swift family, for example, hold the speed record for horizontal flight, darting across the sky at speeds of over 110 kilometers an hour. Bats, in contrast, have always been considered slow because of the greater air resistance resulting from their wing structure. This belief is mistaken, as researchers at the Max Planck Institute for Ornithology discovered. They have identified a new champion among the acrobats of the air: the Brazilian free-tailed bat, which zips through the night at speeds of over 160 kilometers per hour – and that without a tail wind. The bats, which weigh just 12 grams, reach such high speeds thanks to the aerodynamic shape of their body and – for bats – longer-than-average wings.
(www.mpg.de/10820081)

Animals with long, narrow wings usually fly faster than those with broad, stubby wings. The Brazilian free-tailed bat, which can reach speeds of 160 kilometers an hour, is a case in point.

Photos: MPI for Medical Research/U. Mersdorf and M. Fischer (top); MPI for Ornithology (bottom)

Cells on **the Catwalk**

Life is motion and interaction with the environment. This is equally true of cells within an organism, but for cells to get from one place to another, they not only have to be able to move, they also have to interact with their environment. **Joachim Spatz** and his team at the **Max Planck Institute for Medical Research** in Heidelberg are studying how cells manage this. In his search for answers, the winner of the 2017 Leibniz Prize puts cells through their paces on catwalks and obstacle courses to test their adhesive properties.

TEXT **CATARINA PIETSCHMANN**

The adult human body comprises 100 trillion cells – an almost unimaginably large number, a one followed by 14 zeroes. The cells of our bodies form organs such as the heart and kidneys, and tissues such as the skin and nerves. Some drift through the highly branched vascular system in the form of blood cells, while others patrol the body for the immune system. But regardless of the task they perform for the body as a whole, every cell is an individual. "Each must be able to perceive its environment and respond to it," says Joachim Spatz. The biophysicist headed the New Material and Biosystems Department of the Max Planck Institute for Intelligent Systems until the end of 2015. In 2016, he and his team moved to the Max Planck Institute for Medical Research in Heidelberg. Together, they are devising biophysical experiments, measuring techniques and model systems to investigate the motility and adhesion of individual cells and cell collectives.

Many cells have to cover distances of various lengths within the body: during embryonic development, for example, but also during continuous remodeling processes in the adult body, cells must migrate from their place of origin to the sites where they are needed. To do this, they have to know where they are and where they need to go.

RECEPTORS SENSE THE ENVIRONMENT

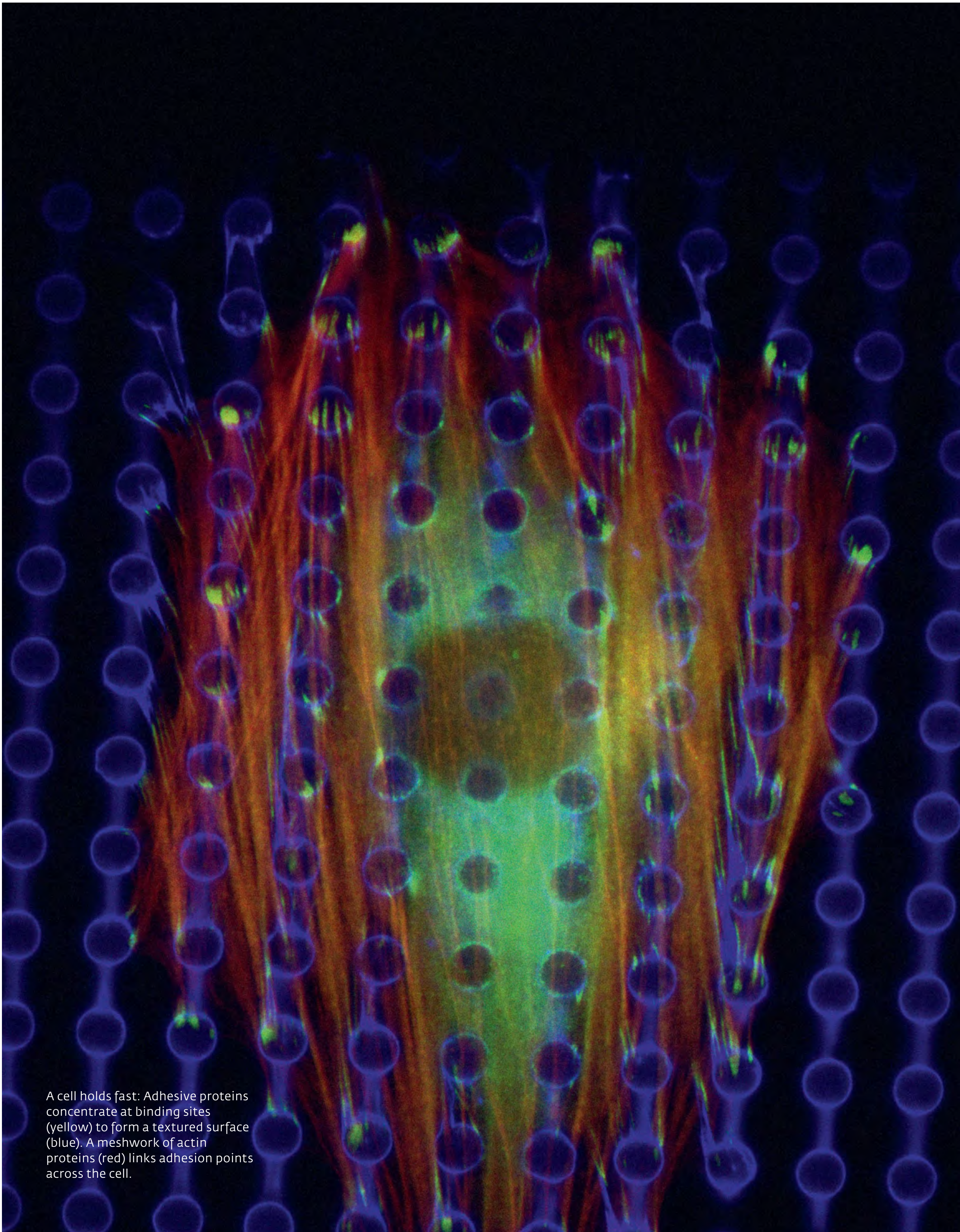
But how does a cell interact with its environment? "For one thing, it detects chemical signals via receptors on the cell membrane," Spatz explains. Small molecules attach themselves to membrane-spanning proteins and activate signaling pathways in the cell's interior. Depending on the information transmitted, genes are revved up, throttled or switched on or off.

In addition, the cell also perceives its underlying surface tactically. It can distinguish whether the surface is hard or soft by essentially tugging on it. "It's like us probing the ground," Spatz says. "If it's soft enough, I can safely fall to the ground. If it's made of stone, I'd better not. "Cells adapt their behavior in a similar manner. "If a stem cell perceives a hard environment, it will mature into bone or tissue cells. If, in contrast, the substrate is soft, it matures into a nerve cell."

Cells are even able to estimate the number of small molecules near them. This gives them a sense of how important the latter are as chemical messengers and whether a response is appropriate. "It is also important for migrating cells to know how densely a surface is covered by molecules," Spatz says. "If the distance between the molecules is 60 nanometers or more, the cells are unable to read the information."

In order to observe the behavior of individual cells, Spatz's coworkers have developed a sort of cellular catwalk, which they call cellwalks. Each cellwalk

Photo: MPI for Intelligent Systems



A cell holds fast: Adhesive proteins concentrate at binding sites (yellow) to form a textured surface (blue). A meshwork of actin proteins (red) links adhesion points across the cell.

Jacopo Di Russo studies the migration behavior of human skin cells and measures the force the cells exert to cling to a surface. To do this, he binds various proteins to gels to alter the properties of the surface.

consists of a polymer surface coated with ultrafine gold particles. The gold acts as anchoring points for biomolecules – peptides, for example, or antibodies, to which, in turn, cell receptors can bind. This provides support for the cell, because without these "nubs," the surface would be far too slippery. By varying the base polymer, the spacing between the anchoring points can be adjusted to 30, 50, 70, 100 or 150 nanometers. For the cellwalk, a small piece of the synthetic surface is placed in a culture dish with nutrient solution. Individual cells are then placed on top of it, the microscope is focused and the camera is activated.

MIGRATION AT A SNAIL'S PACE

How fast do cells actually move? "On average, 30 micrometers an hour, but they can reach a brisk 50 micrometers an hour," says Spatz with a chuckle. They can travel about one millimeter a day, assuming they are fit enough. However, the speed of travel depends on the cell type. Even within a single cell line there are "tortoises" and "hares" because the speed is also determined by the cell's stage of development.

Cells, of course, have no feet, but they do have something similar. They crawl forward on sheet-like extensions, called lamellipodia. The cell membrane bulges out and spreads forward. "It's comparable to us taking a step forward," Spatz explains. The lamellipodium adheres to the substrate by rearranging and aligning protein molecules in the cell's interior – integrins as well as actin and myosin filaments. The rest of the cell body is then pulled forward, and the anchoring site is released again. This process is repeated for each "step" – a form of locomotion also used by amoebas.

In recent years some members of Spatz's team have conducted research not only in Stuttgart but also on the campus of the University of Heidelberg, where word about their work on cell migration soon got around. One day parasitologist Friedrich Frischknecht from Heidelberg University Hospital approached Spatz: couldn't they put a "real" protozoon, namely the malaria organism *Plasmodium*, on the cellwalk for a change?

The tropical disease, which is caused by the bite of an infected *Anopheles* mosquito, still claims half a million lives every year. The mobility of the pathogens, which are injected into the human skin from the mosquito's salivary glands, is crucial for the "success" of the infection. "The sickle-shaped sporozoites move at a top speed of 10 micrometers per second, nearly 100 times faster than human cells," Frischknecht explains. "We're interested in finding out how they do it."

Sporozoites drill through the skin until they reach a blood capillary. They are then carried by the bloodstream to the liver, where they multiply for the first time. Until now it was a puzzle exactly how sporozoites move forward. The only thing that was clear was that they neither crawl nor paddle like bacteria and single-cell algae, because they

Photo: Wolfram Scheible

» Malaria pathogens move nearly 100 times faster than human cells.

form neither lamellipodia nor flagella. "Sporozoites glide gracefully without changing their shape thanks to special proteins on their surface," Kai Matuschewski explains. The scientist at the Max Planck Institute for Infection Biology in Berlin and professor at Humboldt University is the third member of the project.

The *Plasmodium* experiments didn't require a non-slip cellwalk, but an obstacle course to imitate the parasite's relentless progress through the skin. Spatz constructed a miniature bed of nails, of sorts, from polymers through which the parasites can glide as if through a forest of ultrafine needles. A comparison of various mutants, each of which lacks a different protein, yielded fresh insights. "We can now directly observe what actually happens. If protein X is missing, the parasite is unable to hold on; if Y is missing, it sticks fast to the surface," Matuschewski explains.

TINY PROTEIN FEET

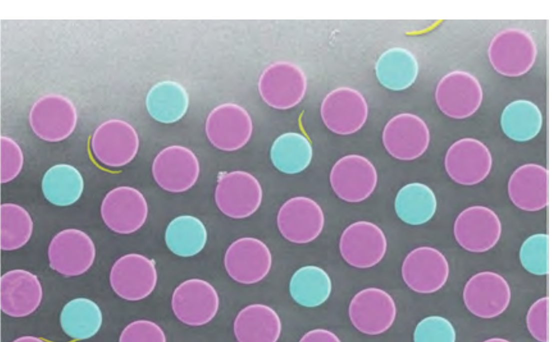
In its cell membrane, a sporozoite has a huge range of proteins that are required for locomotion, some of which perform identical functions. Hundreds of them are situated at the anterior end of the tiny cell body, to which they are connected by a meshwork of actin molecules. "The parasite causes the membrane proteins to move toward the posterior end and then repels them," Matuschuweski explains. The motion is similar to that of a millipede – except that these so-called feet consist only of single molecules and are so small that they can't even be seen under an electron microscope. The force the parasite has to exert to hold and then release itself can be measured with the help of optical tweezers. This provided further insights into how the single-cell organism moves.

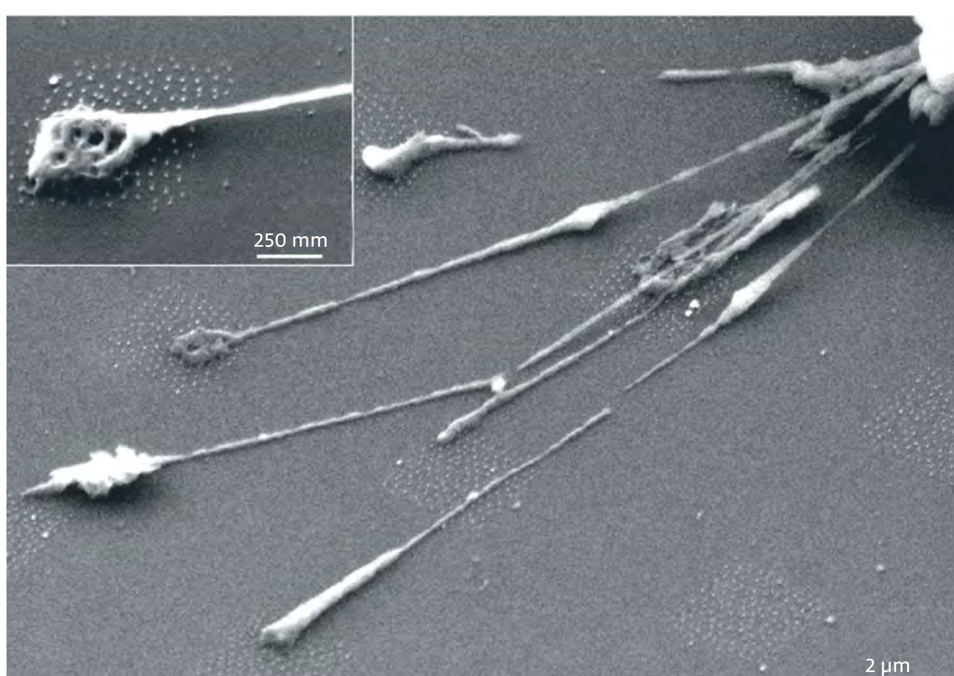
The malaria organism has a complex life cycle, in the course of which

Photos and graphic: MPI for Intelligent Systems (2)

Below Malaria parasites (yellow) crawl over a surface studded with tiny columns. If the single-cell organisms have the same curvature as the columns, the pathogens, which measure just one hundredth of a millimeter in length, begin to circle around the obstacles.

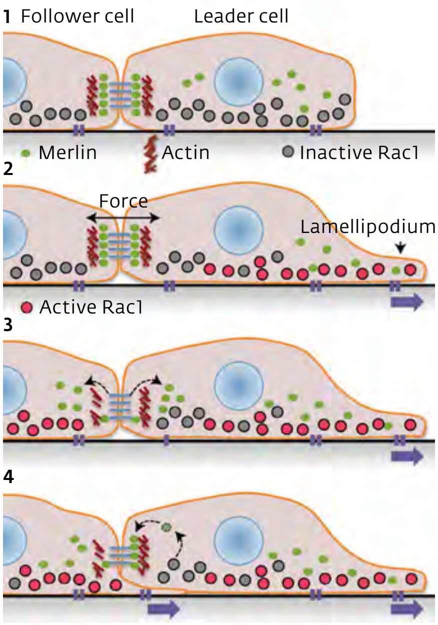
Right A migrating cell. It forms contact points with the surface at specially structured sites located at the ends of thread-like processes (small image). At these points, it senses the properties of the surface and uses the anchoring points to pull itself forward.





Above Jacopo Di Russo, Katharina Quadt and Medhavi Vishwakarma (from left) preparing a new experiment in which they will modify and measure the movement of cell collectives.

Below The protein merlin (green dots) controls the direction of travel of follower cells: **1** Without physical or chemical stimulation, merlin blocks the formation of lamellipodia. Without these protuberances, the cell is unable to move. **2 + 3** If, in contrast, the leader cell pulls on the cell behind it, merlin in both cells leaves its site on the cell membrane, allowing a lamellipodium to form. The follower cells are then able to follow the leader cells. The signal molecule Rac1 (red dots) must also be activated for a lamellipodium to form. The cells always migrate toward areas of higher concentrations of activated Rac1. **4** If Rac1 is inactivated (gray dots), merlin again blocks the formation of lamellipodia at the cell membrane.



it takes on various forms. However, experts agree that the sporozoite is a promising – if not *the most* promising – target for a vaccine, for the sole reason that only around 100 pathogens are present immediately after an infection. In the later stages of infection, there are billions. “Ideal vaccine candidates are antibodies that block two or three of the pathogen’s proteins involved in movement,” Matuschewski says. If the sporozoite is unable to glide, it literally gets stuck in the skin, and the infection is stopped in its tracks.

Having studied the movements of individual cells in detail, Spatz’s team turned its attention to the migration behavior of entire groups of cells. They posed the question: how exactly does a wound heal?

Whether it’s a small cut to a finger, a scraped knee or deep cuts following an operation, epithelial cells have to “rush” into the wound to close it and begin rebuilding the tissue. This sounds simple, but it is a highly complex process. It has been compared to marching in lockstep. Joachim Spatz calls it collective cell migration. It is one of the processes that no longer function properly in chronic wounds.

MIGRATION UNDER A MICROSCOPE

The scientists needed a suitable wound model for their experiments. They covered the bottom of a petri dish with a nutrient medium and grew epithelial cells on it. They blocked a region of the dish to prevent the cells from migrat-

Photo: Wolfram Scheible; graphic: MPI for Intelligent Systems

» Mechanical tension at tissue edges promotes wound healing.

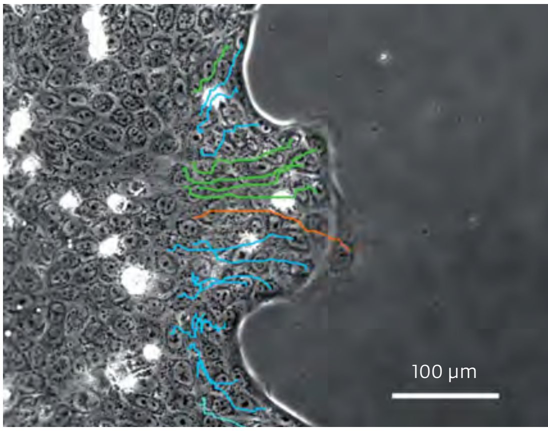
ing into it. As soon as they removed the blockade, the cells started to colonize the free space. Their movements were recorded by a microscope camera, which took snapshots of the process every ten minutes.

After just a few hours, bulges appeared in the originally straight wound edges. "That's because some cells move faster than others," Spatz says. In other words, the repair crews don't advance in ordered lines. Rather, there are leaders, "pioneering" cells that the others trail along behind. "They form the vanguard of the collective and can easily be identified because they're bigger and move ahead of the others."

What makes a cell a leader? And how do they communicate with the other cells in their tow? To answer these questions, the researchers varied their experiments. They covered the bottom of the petri dishes with a hydrogel, which cells find slippery, and sowed the epithelial cells within only a small geometrical shape in the center. As soon as the colonies filled these circular, triangular or square areas, the researchers briefly exposed the gel to UV light. This transformed the slippery surface into a non-slip surface, and the epithelial cells quickly set off. "We found that leader cells tend to form at places with a pronounced curvature, for example in the corners," Spatz says. This is easily explained: the contacts between the cells are mechanically stabilized by what are known as tight junctions – short struts of membrane proteins such as cadherins. If the cadherins of cell A match those of cell B, the extracellular domains of those proteins click together like snaps. At the same time, the actin skeleton in the interior of the cell reaches out to neighboring cells for stability. "The edge of a cell collective is sort of like a herd of sheep that has been penned behind a fence," Spatz says. The actin fence is under mechanical tension. If the curvature is the same everywhere, as in the case of a circle or a straight line, it's difficult to break away from the herd. "Neighboring cells take off together and jockey for the lead. Eventually, one prevails and the others fall behind." However, a cell that marches out of the corner of a square, for example, has no neighbors and automatically becomes a leader. Surgeons unknowingly exploit this effect when they make zigzag scalpel cuts rather than straight ones, thus stimulating subsequent cell migration into the wound.

ONE LEADS, THE COLLECTIVE FOLLOWS

The researchers suspect that, at least in principle, every cell has leadership potential. Whether they can exploit that potential depends largely on their position at the edge of the wound. If the position is not crucial, for example if the edge of the wound is straight, then the cell rows in the rear determine which cell becomes the leader. Ultimately, the decision regarding the leadership of a collective is not made independently by the leader cell, but by the collective as a whole. This decision is physically regulated in the collective by purely mechanical means. The question that remains is how the leader communicates with its followers.



Wound healing in a petri dish: Epithelial skin cells migrate together into a region with no cells. The colored paths show the cells' movements over a period of more than five hours.

The researchers first measured the speed and direction of motion of each cell in a collective. "That showed us that domains of 20 to 30 cells form that then quickly march together in one direction," Spatz explains. These cells form what is termed the persistence length, that is, the distance over which cells march in a coordinated manner in one direction.

Then the real work began. "In molecular cell biology, we know hundreds of proteins that serve as signal molecules for cell migration," Spatz says. "We switched off the gene for each migration-associated protein so that the cell was unable to synthesize that protein. Then we measured the persistence length of the mutants by biophysical means." The scientists were amazed to discover that very few of the proteins

Medhavi Vishwakarma, Freddy Frischknecht, Joachim Spatz, Jacopo di Russo and Katharina Quadt (from left) analyzing data.
The scientists have established that the protein merlin plays a key role in the collective migration of cells.

have anything to do with collective movement. Only if the membrane protein merlin is missing does the collective break apart.

It is astonishing that the cell relies on just a single type of molecule and doesn't have at least one backup protein at the ready. Merlin is not a new discovery – it was already known from cancer biology. Unlike in the case of wound healing, a metastatic growth wants to prevent the cellular "herd instinct" because single cancer cells are more efficient and can progress into tissue more quickly than a group. They let the bloodstream carry them to distant regions of the body, where they establish themselves at suitable locations and begin to divide uncontrollably. "Merlin is a metastasis inhibitor," Spatz explains. "It's a good sign when the protein is very active in cancer cells. The cells then tend to stay together and are thus less likely to form metastases."

It was already known that merlin is positioned between the cell membrane and the cellular skeleton. The researchers observed collective cell migration after labeling merlin with a dye, and found that the protein leaves its original location to reappear in the interior of the cell. But why? They hypothesize that the leader cell rushing ahead creates tension between the cells. "It's like a runner pulling another runner behind him by the hand," Spatz explains. Merlin is like a force sensor that responds to this tension. It disappears into the interior of the cell, leaving room on the membrane for the follower cell to extend its lamellipodium and follow the leader. "If merlin didn't do that, the cell would be unable to follow, because membrane-bound merlin acts essentially as a lamellipodium brake." And because the protein makes room only at places where the leader cell pulls, the direction is automatically established. This process continues down the rows of the cell collective – literally pull by pull. So mechanical tension promotes the formation of cell collectives and thus wound healing.

And how does the lead cell know which direction it must go in? "In our model, it can move in only one direction, namely into the free space. In the case of a real wound, however, signaling substances are released that convey directional information to the cells along the wound's edge." Spatz's team, together with the University of Heidelberg, has since repeated and confirmed the experiments on human skin models.

UNCOORDINATED MOTION WITHOUT MERLIN

The researchers also discovered that, without merlin, more leader cells form, but the wound healing proceeds more slowly, because the mechanism by which the cell collective moves is no longer coordinated.

Spatz is currently also looking more closely at the movement of cancer cells. "Unlike healthy cells, they have a tendency to ignore their environment. That's bad for patients, but good for the cancer!" Metastatic cancer cells reduce not only their merlin production, but also that of cadherin contact proteins. They are therefore able to make themselves extremely long and narrow and slip between tissue cells to invade new regions of the body without being detected or stopped by other cells.

Photo: Wolfram Scheible

However, cell migration is not specific to wounds and cancer cells. It occurs continuously everywhere in the body. "If cells did not cluster together, communicate with each other and migrate together, we wouldn't exist. The migration and interaction behavior of cells was the prerequisite for the evolution of multicellular organisms – and thus for life as we know it."

Communication with the environment is the lifeblood of cells, something they have in common with us, their one-hundred-trillion-cell collectives. What happens to people when communication is cut off for extended periods? They become lonely. Some may become despondent, while others might find that they are sufficient unto themselves. Yet others would seek out old acquaintances or establish new ones. Cells, in contrast, have no choice: they activate a built-in suicide program and die. ◂

TO THE POINT

- **Membrane-bound proteins convey information about a cell's environment, such as the nature of the substrate. By remodeling its internal skeleton, the cell can form small protuberances in the membrane, which it uses to move about.**
- **When epithelial cells migrate into an uncolonized area, some of them become leader cells that the others follow. Such leader cells tend to develop at sites where the tissue edge has a pronounced curvature, for example at corners and edges.**
- **Merlin, a membrane protein, coordinates groups of migrating cells. It senses the physical tension that arises when a leader cell pulls on the follower cells, enabling the formation of small protuberances at the pulling points. The protuberances are then used for locomotion.**

GLOSSARY

Lamellipodia: Broad protuberances of the membrane at the anterior end of motile cells. They are also known as pseudopodia. A two-dimensional meshwork of thread-like actin proteins provides stability and tensile force. Lamellipodia are used for locomotion and navigation, and for engulfing nutrient particles (phagocytosis).

Optical tweezers: A method that allows scientists to measure the forces that individual molecules exert on each other. Each of the molecules to be measured is placed on a plastic bead that is held in position by two laser beams. As soon as the molecules start to interact and attract each other, sensors measure the force that the lasers must exert to hold the beads apart.

A Perspective **for Life**

The discovery that small organic molecules are excellent catalysts makes **Ben List**, Director at the **Max-Planck-Institut für Kohlenforschung**, one of the pioneers of a new research field in chemistry. His life, however, has been shaped just as much by a life-changing vacation experience.

TEXT **CATARINA PIETSCHMANN**

To be able to write about the work of a researcher, it is often sufficient to read a couple of their publications. These, however, don't disclose anything about the individuals themselves. A few hours is usually all it takes to get to know them and be able to sketch a portrait. It was different in this case, because Ben List and I had spent two years doing our doctorates together. That was a long while ago now, and we hadn't seen each other for nearly 20 years, so we had a lot to talk about when we met up again. Ben's life had followed an unusual course since our time together at our university. The Leibniz Prize, which the pioneer received in the field of organic catalysis in 2016, is an occasion to report about it.

The telephone call bearing the news that he is to be awarded the Leibniz Prize reaches Ben List in California on a sunny winter's morning. Perfect timing, as he has been invited to San Diego not only to give a talk – another employer wanted to entice him away. Live and do research here again? To be honest, that was really appealing. A laboratory with a view of the Pacific, where pelicans cruise through the air and whales swim past in January? "But the conditions I have at Max Planck, this autonomy – particularly now with the Leibniz Prize – that simply couldn't be beaten," says Ben List with a smile. The 49-year-old scientist has headed the Homogeneous Catalysis Department at the Max-Planck-Institut für Kohlenforschung since 2005.

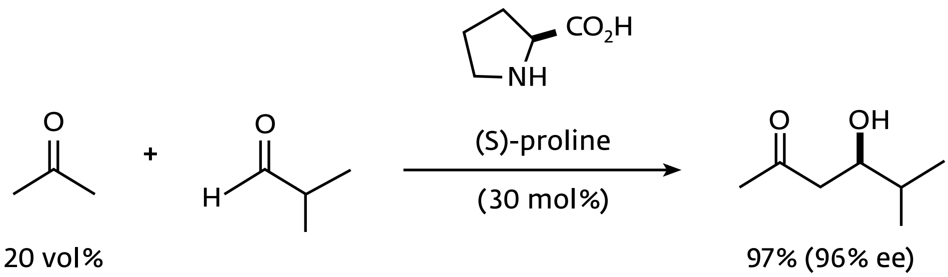
"I WOULD HAVE LIKED TO HAVE HAD A MUSICAL EDUCATION"

If there is such a thing as a researcher gene, it was firmly established in his family long before his time. Jacob Volhard (1834 –1910), a student of Justus von Liebig and, like him, a well-known chemist, was Ben List's great-great-grandfather. His great-grandfather Franz Volhard made his name as a nephrologist. And his aunt "Janni" (Christiane Nüsslein-Volhard), a developmental biologist and Max Planck colleague, received a Nobel Prize in 1995.

He grew up in an upper-middle-class family in Frankfurt, recounts List. When his mother's siblings got together at Christmas, one of Bach's Brandenburg Concertos was on the music stand. "It looks as if I was predestined to take this route. But reality was different." When Ben List is three, his parents divorce. His mother now works full time as an architect, and Ben List and his two brothers go to the *Kinderladen*, an anti-authoritarian nursery school. This type of education was all the rage at that time. "We had to fend for ourselves a lot. I would have liked to have had a musical education at an early age." He wasn't positively encouraged to learn an instrument, though. If the boys were interested in music, it

Photo: Frank Vinken

Yoga in the lab – Ben List is only doing this for the photographer. When he walks into his office in the morning, he has usually already done his exercises.



Above A plan for a new research field: Ben List was the first to catalyze this chemical reaction with the amino acid proline, shown above the arrow – and achieved a yield of 97 percent. One of the two mirror-image variants of the product was formed here with an excess (ee – enantiomeric excess) of 96 percent. Since then, many chemists have been looking for purely organic molecules in order to use them as reaction accelerators.

Below Chemical kitchenette: The apparatus in which chemists produce new substances are usually much more complex than the equipment in most kitchens. They do have hotplates, though.

would happen automatically, was his mother's view. You can do it! You can become anything you want – conductor, artist or a famous chemist. "She always had this confidence," says List looking back.

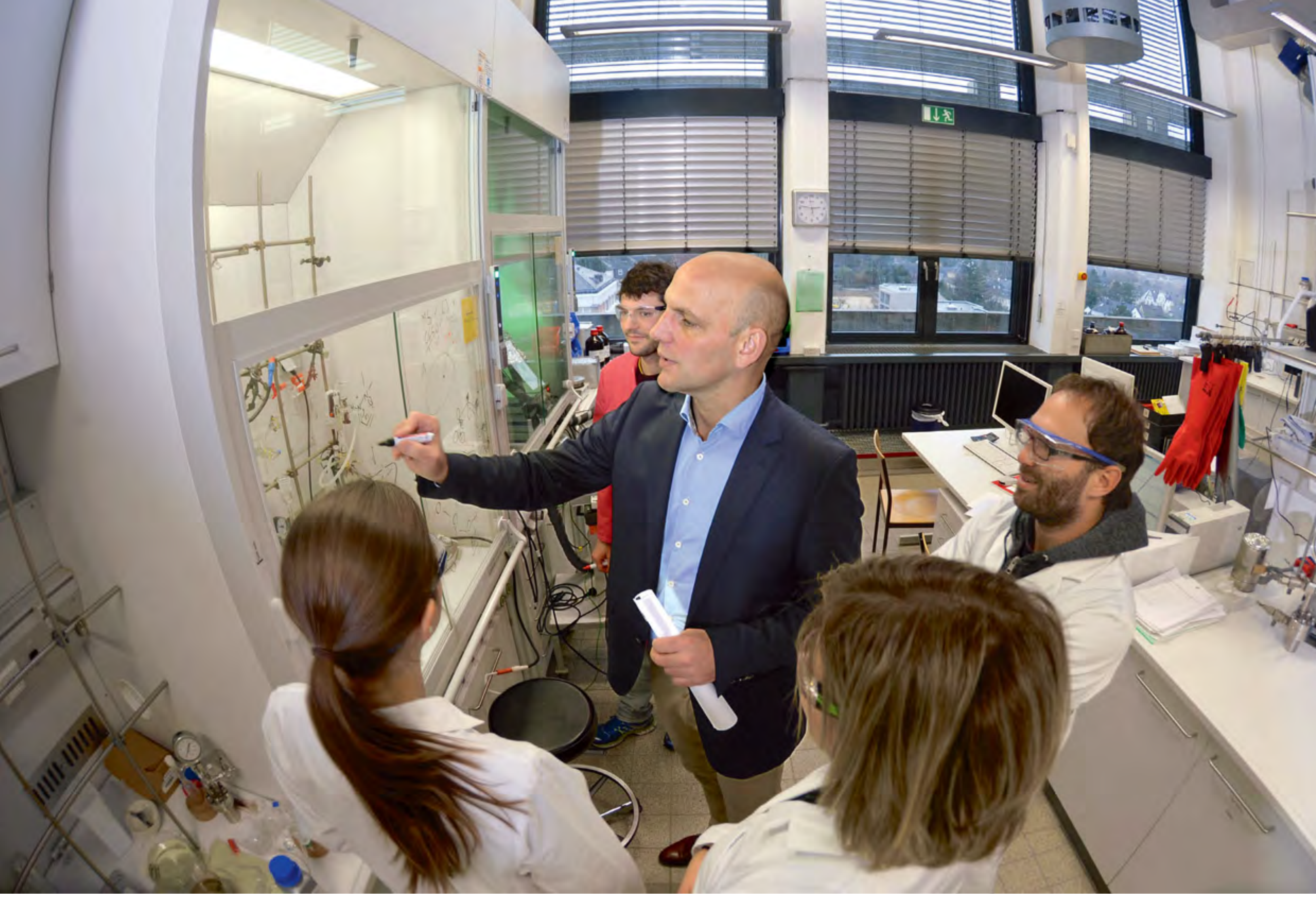
HIS AMBITIOUS GOAL: THE SYNTHESIS OF VITAMIN B_{12}

As a pupil, he was motivated by almost philosophical questions: What is the world made up of? What are human beings made up of? Chemistry promised to provide answers. Back then, List even thought chemists were all-knowing. "Pretty naive," he says today. "But when I found out that they don't have answers for everything, I was already fascinated by the discipline." After receiving his school-leaving certificate, the first thing he did was to spend three months traveling around India with two friends. The others had already made arrangements for their university courses. "I was the only one who hadn't given it any thought at all. When I returned, my mother became surprisingly vehement: Well, Ben, you really should do something now!" Study chemistry, of course, and in Berlin, of course. (A cousin lived there.) List called directory assistance and asked for the number of the University of Berlin. "Which one?" asked the irritated voice at the other end of the line. "Just choose one!" Ben List laughs. "Yes, that is how I landed at FU Berlin."

The third semester courses included organic chemistry, which meant lectures with Johann Mulzer. "They were absolutely perfect!" With no haste and a lot of colored chalk, the specialist for enantioselective natural product synthesis drew gigantic diagrams on the board that he used to show the step-by-step path by which complicated antibiotics or hormones are created. There was no question about it, Ben List simply had to join Mulzer's team.

And he had set himself an ambitious goal: vitamin B_{12} was to become his molecule! One can guess how complex the structure is from its cumulative formula $C_{72}H_{100}CoN_{18}O_{17}P$ – and Mulzer didn't warn him. "In my ignorance, I thought: one half for my bachelor's degree, the other as my doctoral thesis. That was the plan." Vitamin B_{12} was first synthesized in 1972 by Albert Eschenmoser (ETH Zurich) and Robert B. Woodward (Harvard) together. "More than 100 doctoral students and postdocs had spent ten years working on it. And I thought I could do it alone," says List, with a shake of his head. His goal was to produce the molecule more elegantly and in fewer steps – and all by himself. At some stage, Mulzer put the brakes on. It would be sufficient if he managed the two top rings, the "northern side," so to speak. The maiden ascent of a north face was more like it. But List arrived at the peak of the mountain and looked down with pride. There was a "summa cum laude" at the bottom.

Photo: Catarina Pietschmann



That could be it! Ben List and his colleagues team up to develop ideas for new reactions. Not unusual: their blackboard is the front pane of a fume hood, which permits any gases that may be released to be directly pumped out.

Photo: David Ausserhofer

"Assembling a molecule piece by piece is highly elegant and aesthetic, almost a work of art." Chemists call this procedure total synthesis. Reproducing natural products in this way was absolutely en vogue in the 1990s – but total synthesis was never really practical. There were always by-products, which meant complex separation processes and a lot of waste, says List today.

Wouldn't it be better to selectively control reactions with the aid of catalysts – that is, in such a way that only the desired product is produced? Just like enzymes often do in nature? That would be truly elegant! At the end of the 1980s, research into abzymes – antibodies that express catalytic activity, like those formed by the immune system – was a hot-button topic. At the Scripps Research Institute in La Jolla (southern California), Richard Lerner tried to use abzymes to selectively catalyze just about any catalyzable reaction. List had read about it: sounded crazy – but exciting. That was what he wanted to do! "Without asking anybody, of course, let alone my dissertation supervisor." Ben List was used to making his decisions alone – this is where his anti-authoritarian education made itself felt. "I've also used it with my kids from time to time," he adds, grinning. "You may only be 12, but if you think it will do you good to eat ten chocolate bars, then go ahead and do it. I have faith in you. But my advice is: I wouldn't do it."

FROM 1999: THE EXPEDITION INTO HIS OWN RESEARCH FIELD

No advice, however well meant, would likely have put him off going to the Scripps Research Institute. He managed it with a fellowship from the Alexander von Humboldt Foundation. How cool! This is where researchers such as K.C. Nicolaou and Barry Sharpless were working – names well known from chemical reactions or molecules. "They all wore shorts and T-shirts, were addressed simply as 'Bill' or 'Nic' – it was California, after all! The activation threshold to get into conversation was extremely low." There was hardly any need for mediators – in contrast to the situation with many molecules that are set up to react with each other. They need catalysts to lower the energy threshold that inhibits them from coming into contact.

Biocatalysts in particular – that is, enzymes – rapidly accelerate specific reactions, some by a factor of 10^{18}! A catalytic antibody for the aldolase enzyme, which "turbocharged" the process in the Erlenmeyer flask by no less than a factor of 10^8, had just been discovered at the Scripps Institute. Ben List was now able to go for it. "It was a euphoric time. I published 17 papers in renowned journals in less than two years."

After a year, his girlfriend moved over from Germany. They had a very romantic wedding on the beach. At almost

Would also look good in an art gallery: The chemists in Mülheim use the test tubes to investigate the products of chemical reactions.

the same time, Richard Lerner offered him a position as assistant professor at the Scripps Institute. At the beginning of 1999, Ben List set off on the expedition into his own research field with two members of staff.

"I wanted to design small organic molecules that act as catalysts." That was unknown territory. Nobody before him had pursued this concept. The conventional catalysts tried and tested in industry were usually, and still are, mostly based on transition metals, such as palladium, nickel and titanium. They are expensive, often toxic, and have to be separated off again in a complex process. Enzymes do it so much more gently, with simple organic groups such as carboxylic acids, amines and alcohols. "But the organic chemists put hardly any faith in their own molecules."

What was known of the enzyme whose antibody analog Ben List now knows by heart was that an amino group and an acid radical were located at the active center. Amino ... acid!, was going though List's mind. Hadn't he heard something about that at university? In a reaction that was later given the unwieldy name Hajos-Parrish-Eder-Sauer-Wiechert reaction, the amino acid proline had been successfully used as a catalyst – a bizarre thing to do at the time. But what if proline now worked with a mechanism similar to that of an enzyme? And what if it catalyzed other reactions as well?

"YOU THINK: MAYBE THIS WAS A CRAZY IDEA"

List took a glass flask, added a little proline and two reactants, and left it to be stirred overnight at room temperature. It was his first independent experiment. "I was very uncertain. You don't think: Ha! I designed this! And now I'll become world famous! No, it's more a case of: Hmm ... maybe this was an extremely crazy idea. Other people have probably tried this already and also know why it doesn't work."

The next day, the reactants had reacted completely, and 72 percent of the mixture had become one of two possible desired products. "Shortly afterward, we achieved an enantiomeric excess of nearly 100 percent with a similar reaction!" Enantiomers are the two versions of substances whose molecules have the same structure, apart from the fact that one enantiomer is the mirror image of the other. The two versions are chemically so similar that it's difficult to synthesize only one of them. Biologically, the enantiomers usually behave differently: one of them can have a pharmaceutical effect, the other possibly no effect at all or even a harmful one.

It is therefore hardly surprising that the paper that was published in the Journal of the American Chemical Society in 2000 both puzzled and fascinated the scientific community and has since been cited 2,200 times. An organic catalyst! A cheap, edible molecule that exists in the human body and isn't only catalytically active, but is even

Photo: Frank Vinken

» An organic catalyst! An inexpensive, edible molecule that exists in the human body – and is even more selective than any other catalyst before? Amazing!

more selective than any other catalyst before it? How could that be? Amazing! Three months later, a paper by David MacMillan was published: he had discovered a similar reaction almost simultaneously in Berkeley. The doubters now believed it, too.

Then the avalanche started. "At first it was only a few, then later hundreds of groups in the US, Japan, China and Europe were now catalyzing their reactions with proline or similar organic catalysts and publishing their findings. Everyone wanted to be part of the trend. It was completely crazy," List remembers. He himself was in an uncertain situation: he now had a family, only a tiny team and still no tenure. But then finally he obtained a large grant from the National Institutes of Health (NIH).

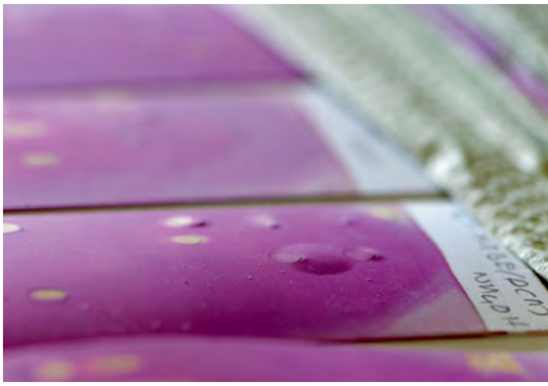
In 2002, Alois Fürstner, Director of the Organometallic Chemistry Department at the Max Planck Institute in Mülheim, visited List in his office. Fürstner had given a talk at Scripps and was surprised. "What? You are German? You have to come back to Germany! To us!" One week later, List flew to Mülheim. He was offered a permanent position, with the prospect of a post as director – and he accepted. By summer 2004, the director's post was already within his reach. Before he assumes the post, List takes his wife and two sons for a vacation in the sun over Christmas – to the beaches of Khao Lak, Thailand. The trip would become a life-changing experience.

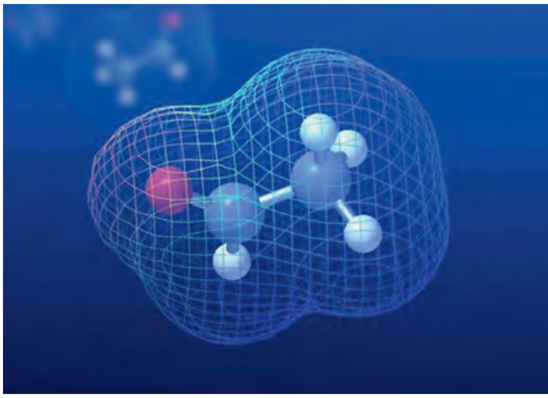
On the last day of their vacation – their suitcases were already packed – they were woken by a tremor. "Probably one of the small earth tremors, we thought, and quickly forgot it again." It was December 26, 2004. After breakfast, they went to the pool one last time. Theo and Paul, his three- and five-year-old boys, are splashing about in the water; Ben List is reading on a chaise longue when he hears a noise that gets louder and louder. He looks toward the beach, and now he hears the shouts. Run! Run! RUN!! "I looked at my wife, we each grabbed one child and started to run."

THE GRAY SLUDGE SWEEPS BEN LIST ALONG WITH IT

The pool hut behind which he seeks cover is made of wood – a piece of cake for the huge tsunami wave. The dirty, gray sludge rises rapidly, sloshes over the roof and takes the hut and Ben List with it. Debris rains down on him. "Paul, who had been in my arms only a second ago, was suddenly gone." Ben List is pushed underwater, briefly surfaces again and is then pulled downward for a long, long time. That's it then … what a pity … a little early, is what is going through his mind. "There was no panic, more astonishment." But he comes to the surface again, starts to fight and saves himself by climbing onto a tree. List has a number of cuts and a large wound on his foot. It had been an extremely narrow escape even for him – Paul couldn't possibly have survived it. He asks around: someone had seen his wife, with a child. Thank God, she had obviously saved Theo. When Ben List finally finds them, it is Paul who is with her.

"He was very pale, with injuries to his rib cage. I'm OK, dad, he whispered." >





Top Chemists use thin-layer chromatography to separate the different products formed in reactions. To this end, they add a solvent to the substance mixture on one side of the chromatography plate. When the solution creeps across the plate, the different products deposit at different locations. The violet color makes it easier for the researchers to recognize the individual substances.

Bottom Unlike other reaction accelerators, the amino acid proline also catalyzes chemical reactions of the small acetaldehyde molecule, which is shown here.

Photo: David Ausserhofer; graphic: MPI für Kohlenforschung

» When you survive something like that, your values change. You are alive, healthy, and you have your family. That's all that matters.

A particularly nice prize: Ben List's uncle alluded to the Leibniz Prize the chemist was awarded in 2016 with a framed Leibniz cookie.

But no trace of Theo. A truck brings them and other injured people 150 kilometers inland to a medical center. While Paul is being treated, Ben List traipses nervously through the rooms. At the very back, a small young boy is sitting on a bed – it is Theo. An Englishman had found him and brought him here. He has only a few small bruises.

ORGANIC CATALYSTS ARE STATE OF THE ART

Unbelievable, they had all survived. "The time afterward was pure euphoria. When you survive something like that, your values change," says List. "You are alive, healthy, and you have your family. That's all that matters." As time passed, normality returned. The trauma was gone, but so was the euphoria. "What has remained until this day is my gratitude for everything I have."

Six months after the tsunami, Ben List becomes a Max Planck Director.

Lying on his desk today are molecules of catalysts, models from the 3-D printer. Compared with the newest catalysts from List's lab, proline looks like David next to Goliath. "Since relatively large amounts of proline are needed, we searched for more effective molecules." With the most recent candidate, a tree-like branched phosphoric acid ester, one forty-thousandth of the amount of proline needed is already sufficient. And this catalyst accelerates reactions that couldn't be catalyzed at all before!

Organic catalysts have since become state of the art. There is hardly a pharmaceutical or chemical company that doesn't work with them. The technical production of several drugs, including the HIV drug Darunavir®, involves organic catalysts such as proline.

This is almost history as far as Ben List is concerned. Working together with the textile research institute in Krefeld, he has since chemically bonded more advanced catalysts to nylon fabric with the aid of UV light. A heterogeneous catalyst is thus formed from a homogeneous one that, like the reaction partners, for example, is dissolved in a liquid. This has enormous advantages for use in chemical production, because unlike homogeneous catalysts, heterogeneous ones don't have to be separated from the reaction medium. "We put a piece of cloth into the glass beaker, add the liquid reagent and stir. We then decant it, quickly rinse the cloth and can then reuse it." And we can do this at least 400 times, as a very patient doctoral student incidentally discovered.

Materials coated with catalysts aren't only of interest for the production of chemicals. "Conceivable ideas include covers for furniture, curtains or carpets that clean themselves when you put water on them." After all, detergents also contain catalysts to break down dirt – just that these disappear in large amounts in the waste water and pose problems for water treatment plants. "The only question is what the detergent manufacturers will think of our idea," says Ben List, laughing.

LIST IS A CHEERFUL, OPEN PERSON

Now he is thinking about catalytic drugs: monoclonal antibodies armed with a catalyst that bond to cancer cells and convert a non-toxic active substance into a toxic drug only when it actually arrives at the tumor. "Selective organocatalysis is interesting for other areas as well, for instance in the production of fragrances or in pest control."

Unlike his doctoral supervisor, who really belittled those in his seminars who struggled with chemical brainteasers, sometimes in front of everyone (as the author remembers), Ben List is considered to be more of a soft boss. He has found his own form of "postmortem." "I call it the shit sandwich," he says with a smile. "Excellent talk! Well done. The less pleasant (middle) part follows in private: This and that could be better. And that was rubbish! Finally, the encouraging base: But I believe you have talent, and we can do this together!"

List is a cheerful, open person – completely at ease and always attentive. His calm, positive air is conducive

Photo: David Ausserhofer

Relaxed thanks to a borderline experience: After Ben List and his family survived the 2004 tsunami in Thailand, the researcher knows that his career and his award are nice, but he could also live without them.

to a creative working atmosphere. “In my experience, creativity never emanates from concentration and stress. Your thoughts can only flow when you are relaxed.” And he has physically created this space for himself as well – by moving the department up to the tenth floor of the Institute. Through a long wall of windows, there is a commanding view of the countryside. On the left, the industrial plants of Duisburg, some of which are already museum pieces; in the middle, a lot of forest around Mülheim and Oberhausen; and on the very right, the outskirts of Essen and in the distance Düsseldorf. When List walks into his office in the morning, he has already done his yoga exercises. He grins. “Standing on your head gives you a different perspective on a lot of things.”

A small Buddha figurine stands next to the group of chairs, a present from his wife. It is a symbol of their shared love of Asia – but also a reminder of how fragile life is. Looking back, List sees the borderline experience as something positive, because it made him realize what really counts. His career, all the awards on the wall behind his desk – one of the nicest is a framed Leibniz cookie with best wishes from his uncle – that’s fantastic. But life would be possible without all this. Maybe it is this insight that gives Ben List the inner freedom to steadfastly go his own way. After all, what’s the worst thing that could happen? ◂

GLOSSARY

Abzyme: The neologism coined from “antibody” and “enzyme” designates an antibody that has a catalytic effect.

Enantiomers always occur in pairs. Chemically, both variants have an almost identical structure but they differ in the spatial arrangement of their molecular parts, like an original and its mirror image, or the right and left hand that can’t be made fully congruent. They behave in largely the same way physically and chemically; it is only with other enantiomers that they react differently. Most biomolecules, such as amino acids and sugars, exist only in the form of one enantiomer, which is why enantiomers have different physiological effects.

Organocatalysis describes the selective catalysis with relatively small, purely organic molecules in which a metal isn’t part of the active principle. Until their catalytic effect was discovered, conventional wisdom held that only enzymes and metal catalysts were suitable for selective catalysis.

Photo: David Ausserhofer

Algae, like most higher plants, use the enzyme RuBisCO to fix carbon dioxide. RuBisCO is the most commonly used biocatalyst for this purpose, but it isn't the most efficient. Scientists are therefore experimenting with other enzymes and metabolic processes to more efficiently convert carbon dioxide into organic molecules.

Metabolism 2.0

Over 50 million genes and 40,000 proteins: combing through international databases for likely candidates, **Tobias Erb** and his colleagues at the **Max Planck Institute for Terrestrial Microbiology** in Marburg were faced with an overwhelming choice. In the end, the scientists picked out just 17 enzymes for the first synthetic metabolic pathway that is able to convert carbon dioxide into other organic molecules. Now they have to show that the cycle they sketched out on the drawing board also works in living cells.

TEXT **KLAUS WILHELM**

It sounds almost too good to be true: a means of counteracting the greenhouse effect, removing excess carbon dioxide from the atmosphere and turning it into environmentally friendly products. Carbon dioxide levels have risen by around 30 percent during the past 100 years, contributing greatly to global warming. A method that removes excess carbon dioxide from the atmosphere while also serving practical purposes would thus be extremely welcome.

Nevertheless, Tobias Erb's primary aim isn't the fight against climate change. The researcher first wants to understand how gaseous carbon dioxide can be converted into organic molecules. "Of course, if we could exploit the greenhouse gas as a carbon source using biological methods and remove it from the atmosphere in the process, that would be a great side benefit," says the Max Planck researcher.

Erb studied biology and chemistry, and even at an early age was fascinated by the question of what makes life tick down to the smallest scale. "I've always been interested in how microscopic life forms, such as bacteria, do things that chemists can still only dream about," he says. Erb spent the first years of his research career studying bacterial enzymes – protein biocatalysts that initiate, accelerate or halt chemical reactions.

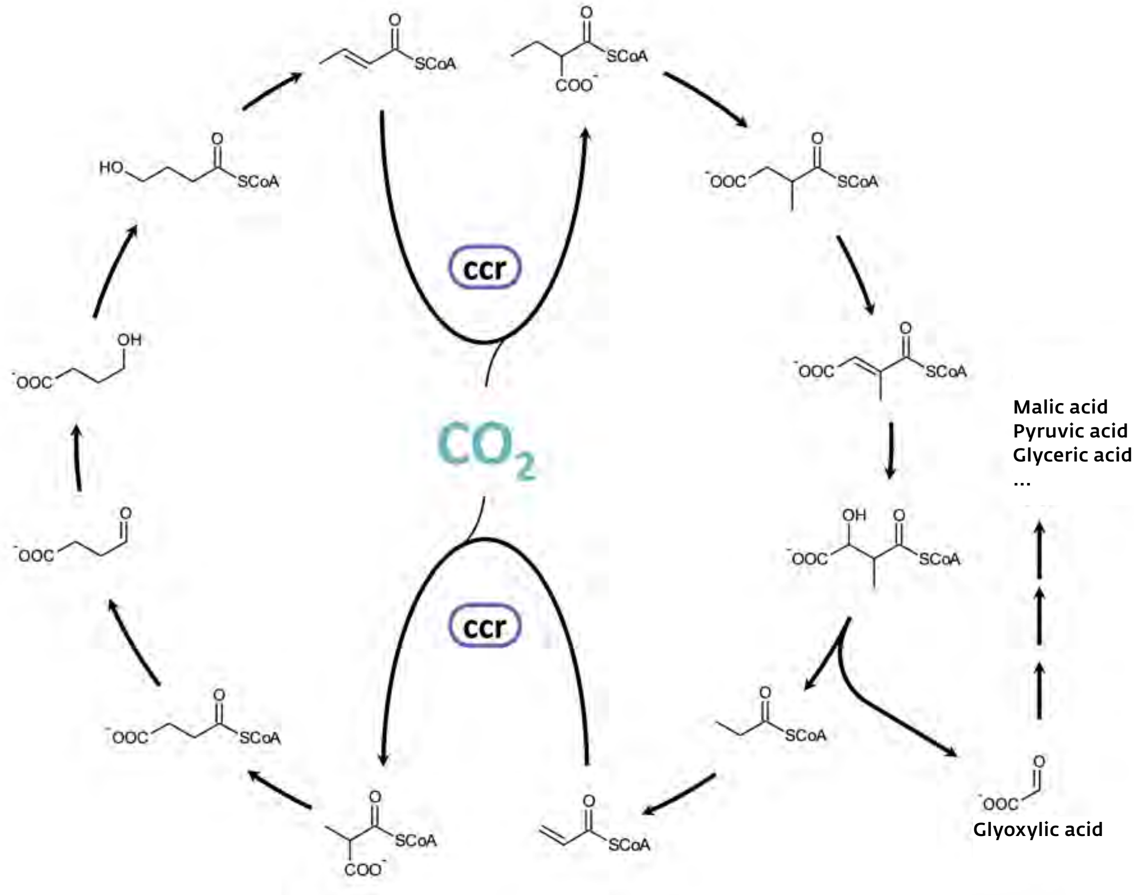
ALTERNATIVE TO RUBISCO

In his doctoral thesis, Tobias Erb turned his attention to the carbon cycle, the process by which atmospheric carbon dioxide is converted into various sugar compounds. In a purple bacterium, he discovered an enzyme with the unwieldy name crotonyl-CoA carboxylase/reductase (CCR). This introduces carbon dioxide molecules into the bacterium's metabolism.

Besides bacteria, plants are the main users of this process, known as carbon dioxide fixation. During photosynthesis, plants harness sunlight as an energy source to produce sugar from atmospheric carbon dioxide. To do this, they use a metabolic pathway known as the Calvin cycle, which is described in every biology textbook along with all the enzymes involved. The Calvin cycle is essential for life on Earth, as plants use it to produce vital organic molecules, such as sugars, for other life forms.

For a long time, the Calvin cycle was believed to be the only pathway for carbon dioxide fixation. "But we've since discovered a good half dozen more," Erb explains. "More than a third of the carbon dioxide on this planet is bound by microorganisms." Nature has thus devised various solutions to the same problem. They all work, but none is perfect.

One example is the carbon-dioxide-fixing enzyme in the Calvin cycle called RuBisCO. Erb describes it as "the most underestimated enzyme on our planet because it's the most common." For every person on Earth, there are around five kilograms of RuBisCO in the biosphere. The enzyme is able to produce a pinch of sugar from the carbon dioxide contained in the volume of a normal living room. Nevertheless, RuBisCO works relatively slowly and



rather sloppily: in a fifth of reactions, the enzyme erroneously grabs an oxygen instead of a carbon dioxide molecule. Plants can afford such a cavalier approach to energy efficiency, as they usually have sufficient light and therefore energy available.

The CCR enzyme Erb discovered, in contrast, acts as though it were turbocharged: it is 20 times faster than plant RuBisCO and fixes carbon dioxide two to three times more efficiently – not least of all because this enzyme practically never makes an error. "CCR catalyzes the most efficient carbon-dioxide-fixing reaction we know of," the biologist says. It is essential for many bacteria because they often have less energy available.

Erb and his colleagues don't just want to find out how CCR works and what accounts for its amazing abilities; they also want to use the enzyme to mimic the carbon cycle in the lab and harness its abilities. "The challenge for us biologists today is to replicate life processes from the inanimate," the researcher explains.

Other scientists have also set their sights on this goal. "Like the analytical chemists in the 18th century, we biologists have tried to break down complex natural processes into individual building blocks in order to understand them," says Erb. "But we will truly understand how biological processes work only when we've reconstructed them from basic building blocks."

LIFE FROM A PETRI DISH

Biology entered a new era – a phase of creation and construction – when it became possible to sequence the genome of any desired organism and to create artificial versions of genes. The magic words: synthetic biology. Scientists working in this field want to create cells that they can reprogram to carry out new functions. One of the pioneers in the field is Craig Venter. His approach is to strip living cells of all components that aren't absolutely essential for survival, thus creating a minimalist cell that can then be endowed with new properties. The American scientist has already synthesized the minimum genome of a bacterium in the lab and placed it in an empty, DNA-free bacterial shell.

In Germany, a project initiated in 2014 by the Max Planck Society and the German Federal Ministry of Education and Research aims to promote synthetic biology. Groups from nine Max Planck Institutes and the University of Erlangen-Nuremberg are participating. Unlike many other synthetic biology projects, this one aims to construct a minimum cell from individual components.

Through this bottom-up approach, artificial cells with specially designed metabolic pathways might one day be created that produce drugs, vaccines or biofuels from carbon dioxide in the atmosphere.

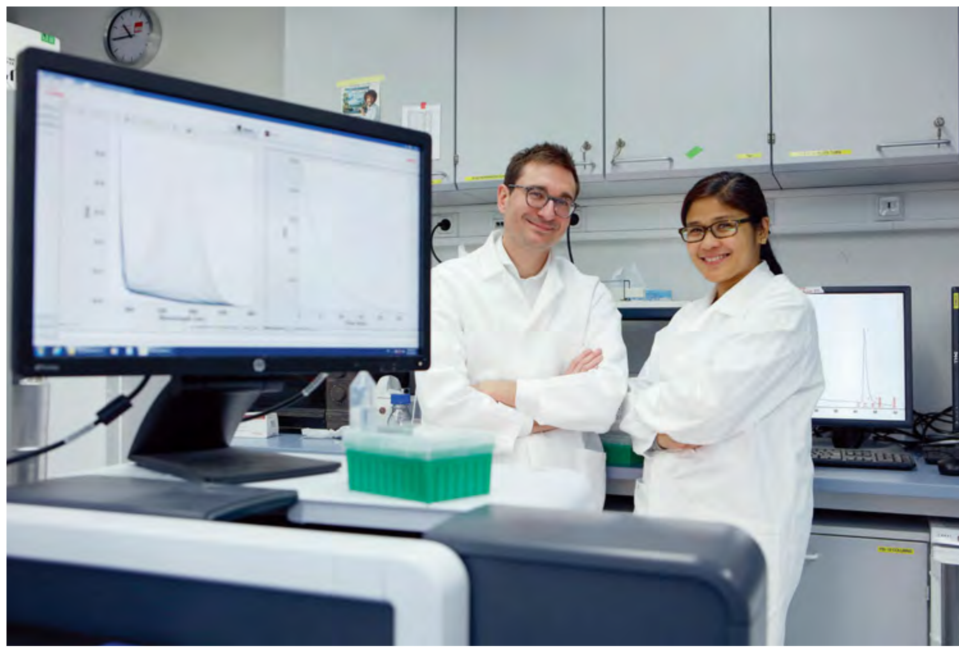
Back to the laboratory of Erb and his team: Thomas Schwander opens the freezer and collects a wide assortment of small vessels, each about half the size of a memory stick. They contain a scientific breakthrough: the substances and enzymes that together

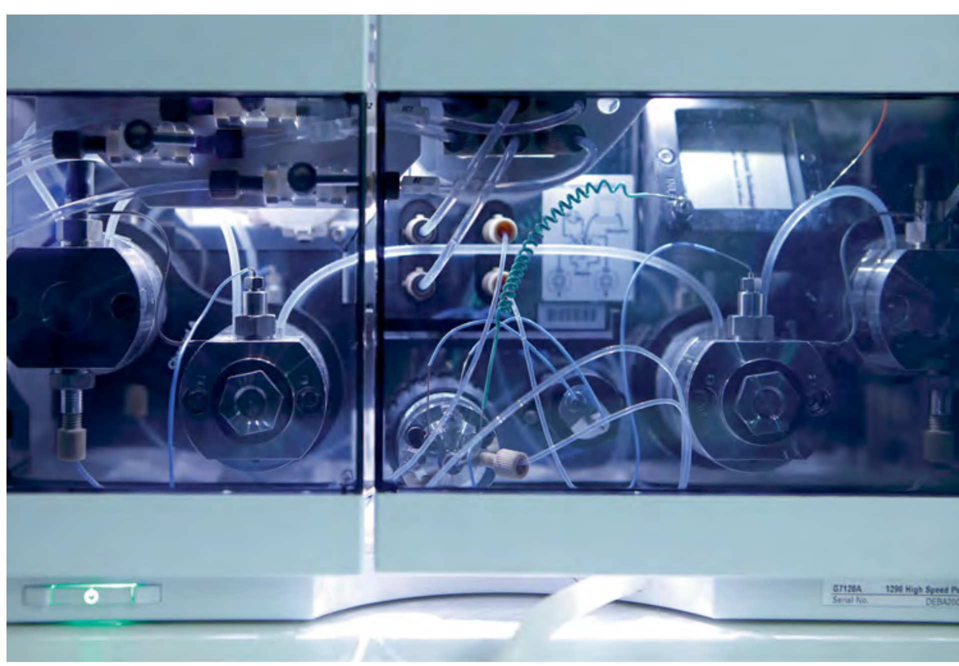
Graphic: MPI for Terrestrial Microbiology

Left page A specific enzyme is responsible for every reaction in the CETCH cycle. Crotonyl-CoA carboxylase/reductase (CCR), for example, facilitates the two carbon-dioxide-fixing reactions.

This page, top Together with Tobias Erb, Nina Cortina is investigating the CETCH cycle. The Philippine scientist is an expert in mass spectrometry. In the foreground is a photospectrometer for carrying out measurements on enzymes.

This page, bottom The researchers use such mass spectrometry instruments to analyze the reaction products of the CETCH cycle.





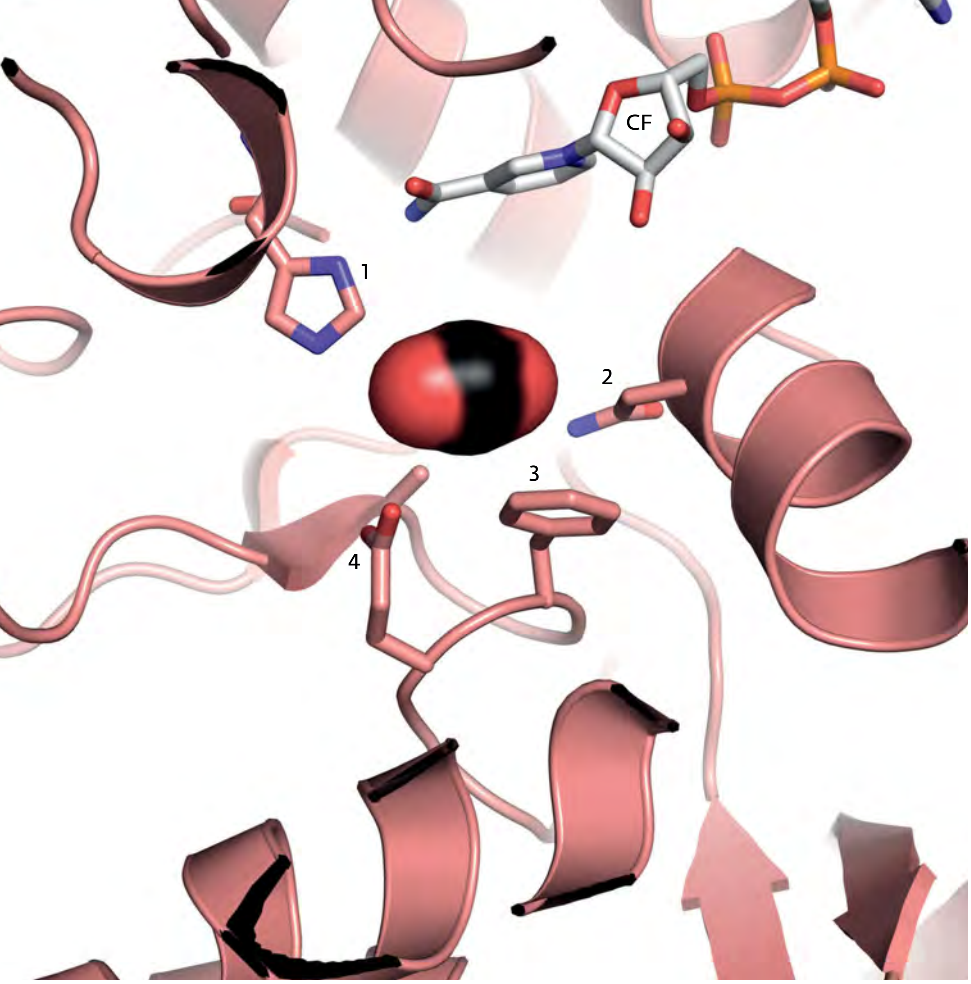
form a completely new metabolic pathway for carbon dioxide fixation.

In 2011, Tobias Erb – then at ETH Zurich – outlined the cycle, called CETCH, complete with all the relevant biochemical reactions, in just two weeks. In addition to drawing on his knowledge of carbon dioxide metabolism, he consulted international databases listing more than 50 million genes and more than 40,000 enzymes and their respective functions.

From those, Erb selected several dozen candidates that, together with the turbocharged CCR enzyme, could perform the desired functions in his artificial cycle: “After studying the natural process of carbon dioxide fixation for so long, I was convinced that our designer pathway could also be realized in practice.”

Even before moving from Zurich to the Max Planck Institute for Terrestrial Microbiology in Marburg, Erb set up a team “without hierarchies and with talented researchers who want to push scientific boundaries.” Applying passion and consummate expertise, they trans-

Photos: Thomas Hartmann (2)



Left The active center of the CCR enzyme (pink lines and bands; CF: cofactor NADPH): The position of the egg-shaped carbon dioxide molecule in the center was modeled on a computer. The amino acids important for positioning the carbon dioxide molecule are shown enlarged: histidine (1), asparagine (2), phenylalanine (3) and glutamate (4).

Right Erb first designed the CETCH cycle on the computer and later tested it with his team in the lab. The result: the first artificial carbon-fixing metabolic pathway.

lated their model from the drawing board into reality in a record time of just two years.

The scientists tested the functionality of new enzyme candidates, modified them and tried out new combinations until they worked optimally together. "Despite all the laboratory technology, this still involved a lot of manual work," says Thomas Schwander. "Time and again we had to overcome new hurdles." For a long time the researchers were unable to get the cycle going because one of the enzymes only worked with an iron compound, which, however, caused the other proteins to flocculate. The enzyme therefore first had to be modified so that it could work with the more suitable substrate oxygen.

Another difficulty lay in that fact that the cycle was initially plagued by numerous unwanted side reactions. As a result, it was slow and tended to grind to a halt quickly. It was only when the scientists added other enzymes to the original design that they were able to eliminate the unwanted reactions. These additional enzymes acted as recycling forces to correct the errors of the other enzymes. Tobias Erb suspects that such corrective loops may also play an important role in natural metabolic pathways.

Despite all the difficulties, the researchers ultimately succeeded in cobbling together the first man-made metabolic pathway for carbon dioxide fixation. It involves 17 enzymes from nine different organisms and includes three designer enzymes that the scientists modified from existing enzymes with the help of a computer so that they work more precisely or catalyze other reactions.

RAW MATERIALS ON TAP

The enzymes are therefore natural in origin, but their combination to form a novel, highly efficient metabolic pathway doesn't occur in nature. "Presumably, the enzymes never had the chance to come together in nature in the course of evolution," Schwander says. Erb's carbon dioxide cycle culminates in the formation of a compound called glyoxylic acid. However, the cycle could be modified to produce raw materials for biodiesel or other organic substances instead.

Carbon dioxide fixation requires energy. The CETCH cycle is driven by chemical energy or, more specifically, by electrons. The Calvin cycle of photosynthesis works with solar energy, which is then converted into chemical energy. The researchers were therefore able to compare the two processes to determine which is more efficient. Whereas the CETCH cycle consumes only 24 to 28 light quanta to bind a carbon dioxide molecule, natural photosynthesis takes 34. "So we could fix about 20 percent more carbon dioxide with the same amount of light energy," Erb points out.

And that's not even the upper limit. Erb's team is already working on developing even thriftier carbon dioxide cycles. In the future, these synthetic fixation cycles might be coupled with solar cells. The electrons the solar cells produce from sunlight could be used to convert carbon dioxide into other compounds. Such visions no longer appear technically unfeasible. For example, researchers in the MaxSynBio network

Graphic: MPI for Terrestrial Microbiology

are working intensively on processes at the interface between chemistry, materials science and biology.

In the context of synthetic biology, the CETCH cycle could also help to improve natural photosynthesis. However, the genes for the enzymes involved in the CETCH cycle would first have to be inserted into a living cell – a bacterium, an alga or a plant – which would then synthesize the desired product.

In the next step, the Marburg-based scientists want to engineer bacteria to use the CETCH genes as intended. “We can’t predict how our cycle of 17 reactions will behave in a cell in which 3,000 reactions of all kinds are taking place. We still have a few more years of work ahead of us,” says Erb.

The biomodule of the CETCH cycle may eventually end up in Craig Venter’s minimalist cell – or even better, in an artificial cell to be created by the MaxSynBio network. In any case, it will still take some time for Erb’s dream of “creating an artificial metabolism 2.0 that is able to produce any desired organic compound from carbon dioxide” to become a reality. ◂

Photo: Thomas Hartmann

TO THE POINT

- **The carbon-dioxide-fixing plant enzyme RuBisCO works slowly and frequently makes errors. By comparison, the bacterial enzyme crotonyl-CoA carboxylase/reductase (CCR) is around 20 times faster and more accurate.**
- **Together with 16 other enzymes, the CCR enzyme can be added to a test tube to produce the CETCH metabolic pathway. The artificial cycle converts carbon dioxide more efficiently than the Calvin cycle used by plants.**
- **Bacteria and plants could one day use the CETCH cycle to fix excess atmospheric carbon dioxide and convert it to useful organic substances.**

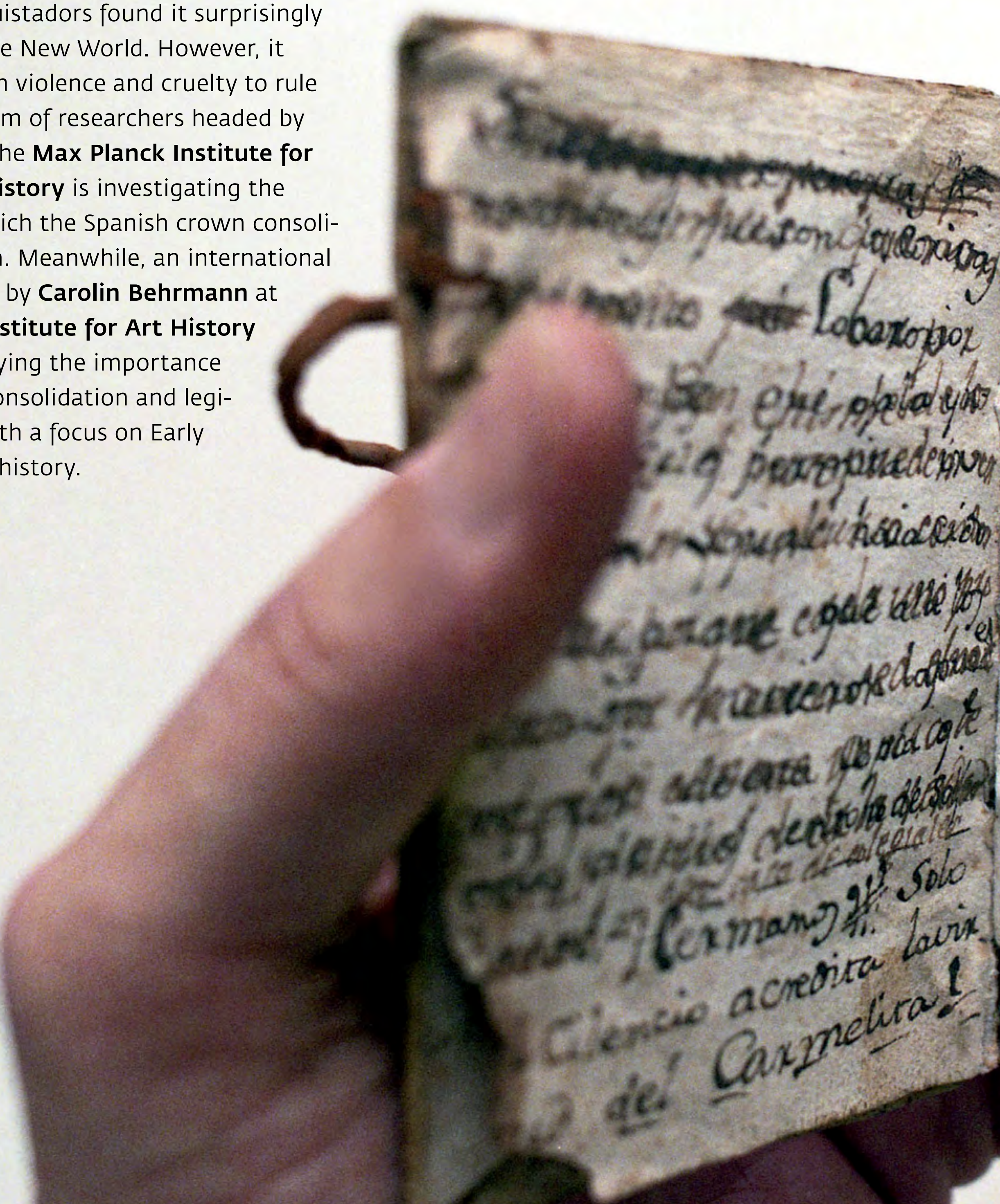
GLOSSARY

Calvin cycle: A metabolic pathway in plants in which atmospheric carbon dioxide is converted into sugar molecules. The cycle uses ATP as an energy source. The enzyme RuBisCO makes it possible to convert carbon dioxide to the sugar ribulose-1,5-bisphosphate (carbon dioxide fixation). The cycle must run three times, fixing three carbon dioxide molecules to produce one molecule of the sugar. The chemical energy required for the Calvin cycle is obtained from the light reaction of photosynthesis.

Synthetic biology: A young research field whose aim is to develop biological systems that don’t occur in nature. A first step is the construction of the simplest possible cell whose genome contains only information that is absolutely essential for the cell’s survival. There are two opposing approaches: some researchers try to reduce the complexity of existing cells to the bare minimum (top-down approach), while others aim to identify the building blocks that are absolutely vital for the cell’s survival and use them to construct new cells (bottom-up approach). The objective is to simplify existing biotechnological processes, but completely new products such as vaccines, medicines, diagnostic aids, biofuels and tailor-made materials could also be designed with the help of synthetic biology.

Ruling
by the Book and the Cross

The Spanish Conquistadors found it surprisingly easy to conquer the New World. However, it required more than violence and cruelty to rule the territory. A team of researchers headed by **Thomas Duve** at the **Max Planck Institute for European Legal History** is investigating the media through which the Spanish crown consolidated its dominion. Meanwhile, an international research group led by **Carolin Behrmann** at the **Max Planck Institute for Art History** in Florence is studying the importance of images in the consolidation and legitimation of law with a focus on Early Modern European history.



Handy and practical: Handbooks such as this prayer book helped priests and friars bring Christianity to the New World and, at the same time, establish the new system of law.

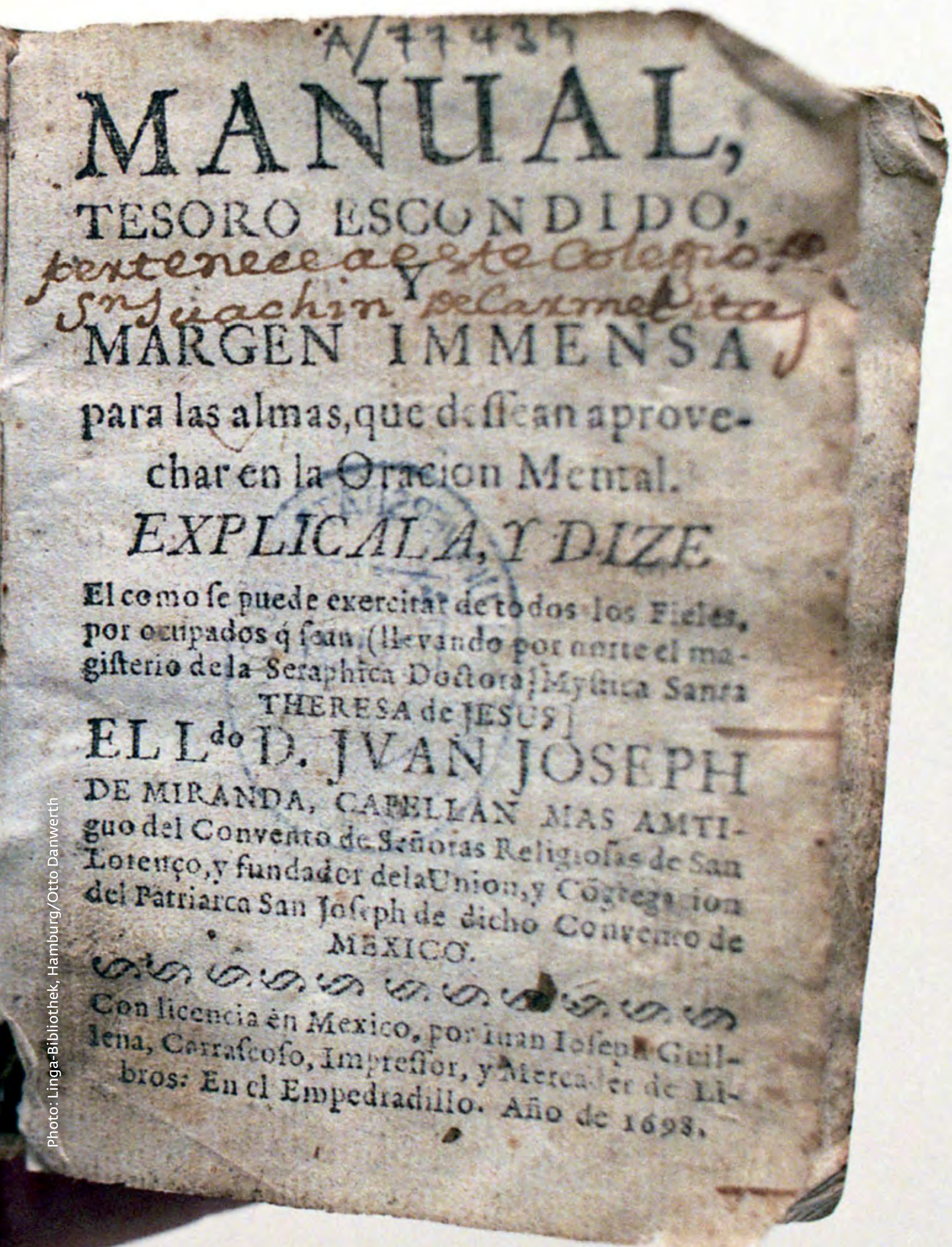

MANUAL,
TESORO ESCONDIDO,
Y
MARGEN IMMENSA
para las almas, que dessean aprovechar en la Oracion Mental.
EXPLICALA, Y DIZE
El como se puede exercitar de todos los Fieles, por ocupados q̃ sean, (llevando por norte el magisterio de la Seraphica Doctora, y Mystica Santa THERESA de JESUS)
EL Ldo. D. JVAN JOSEPH DE MIRANDA, CAPELLAN MAS AMTIguo del Convento de Señoras Religiosas de San Lorenço, y fundador de la Union, y Cógregacion del Patriarca San Joseph de dicho Convento de MEXICO.
Con licencia en Mexico, por Iuan Ioseph Guillena, Carrascoso, Impressor, y Mercader de Libros: En el Empedradillo. Año de 1698.

Photo: Linga-Bibliothek, Hamburg/Otto Danwerth

TEXT **MICHAELA HUTTERER**

The year is 1552, and Portuguese printer João de Barreira is lifting the leaves of a book from his printing press in Coimbra. One thousand pages in easily handled octavo, which he will later bind in modest goatskin. The first page proclaims it to be a "Manual de Confessores y Penitentes." The author of this Manual for Confessors and Penitents was Martín de Azpilcueta, one of the leading canon lawyers and moral theologians of the age. Azpilcueta, or Dr. Navarro, as he is known on account of his origins, was a man of clarity and learning, an adherent of late scholasticism, member of the highly respected school of Salamanca and a recognized authority throughout Europe. Over 50 of his works are concerned with Catholic canon law, moral theology, criminal law and economic theories – large-format books for academic use.

What moved this professor of canon law to disseminate his knowledge for practical use, and in paperback format at that? Could he have had any idea that this very work would become one of the most important sources of advice on day-to-day legal matters – in Spain and across the Atlantic, in the New World?

BESTSELLER IN THE NEW WORLD

"Few if any books in the second half of the 16th century were printed, translated and compilated more often than Azpilcueta's handbook for confessors," says Thomas Duve, Director at the Max Planck Institute for European Legal History in Frankfurt. "And few, if any, were more widely disseminated in the New

» The clerics in the New World were skilled at integrating indigenous beliefs and contexts into the Catholic faith.

David Rex Galindo, Otto Danwerth, Manuela Bragagnolo and project leader Thomas Duve (from left) are investigating the role of simple clerics in consolidating Spanish dominion in Central and South America.

World." In other words, it was a bestseller. Duve's team, comprising Manuela Bragagnolo, Otto Danwerth and David Rex Galindo, have so far found more than 80 editions in archives and libraries in South and Central America and in Europe. Working in cooperation with a collaborative research center in Frankfurt, the scientists are focused on the issue of how, after the conquest, the Spanish crown managed to instruct its overseas subjects to adhere to European norms. How did they impose the law in their area of occupation? Which legal sources and which media were material in implementing codes of conduct in this way?

Investigations into the production, ownership and circulation of books show that scribes, officials, priests and bishops preferred to consult slim compendia rather than wordy volumes. In the New World monasteries and offices of the 16th and 17th centuries, the few official legislative texts were far outnumbered by summaries, commentaries, breviaries and so-called epitomes: excerpts from important works of moral theology and canon law were often compressed into tabular form.

For Thomas Duve's group, these "pragmatic" texts and the approaches of the pragmatici, or semi-scholars, that were based on them are particularly exciting. "As legal historians, we are keen to understand how a relatively small group of invaders was able to dominate broad areas with highly developed populations – quite apart from how we would view such activities from today's perspective. To do this, we must consider all kinds of evidence that can give us insights into day-to-day life and its legal problems," says Duve, explaining his research approach. He is reconstructing the means by which a new normative order was able to develop. The team is interested not just in the sophisticated literature of law, but also in works to which little value has generally been attached in traditional legal history research. Works that become accessible as important sources only with the aid of import documents, inventories of book owners and library lists. These records date from the time shortly after the eminently infamous conquistadors Hernán Cortés and Francisco Pizarro had overthrown the empires of the Aztecs and Incas. The former centers of power were destroyed and Spanish cities and settlements built upon their ruined walls. In 1573, King Philip II of Spain issued what amounted to an urbanization program entitled "Ordenanzas de descubrimiento, nueva población y pacificación de las Indias". By this time there were already 250 towns and cities in existence. It was the rural areas that presented difficulties. How did a common code of conduct, adhered to by both settlers and indigenous people, come to be established in border areas, where there were few, if any, official guardians of law and order?

"The Church was of decisive importance," explains legal historian Thomas Duve. It provided support for administrators and founded monasteries, churches and schools. Between 1511 and 1620, more than 30 dioceses were established. Without this support, the colonization process based on violence and force of law could not have survived. The number of clerics who journeyed to America in the 16th century, some 5,400, far exceeded the total of royal administrators.

It was Franciscans, Dominicans and Jesuits who studied the regions and their people, learned the indigenous languages and thereby established the

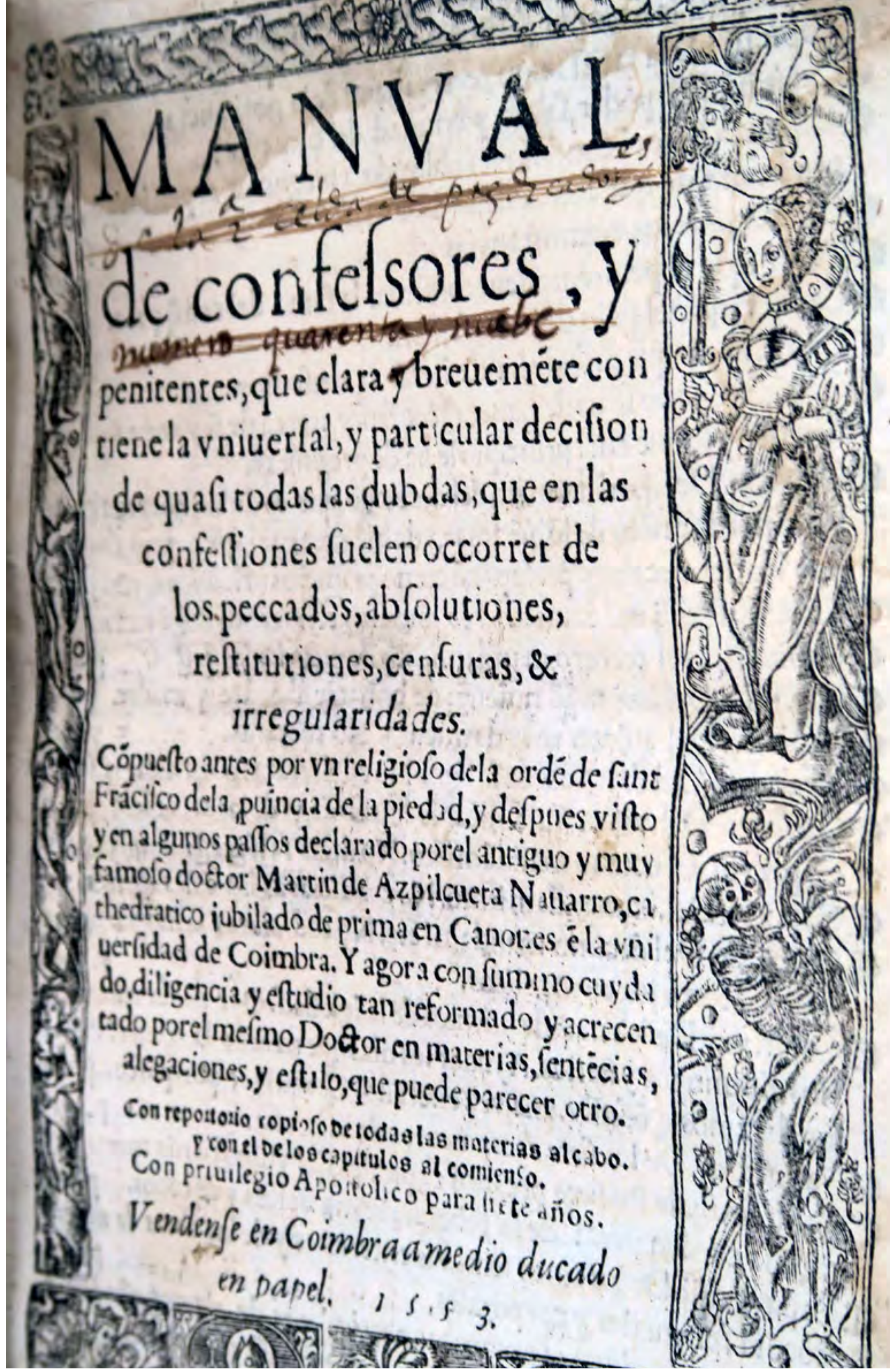
Photo: Michaela Hutterer

Catholic faith with its values and rules of conduct. They transmitted the basic principles of coexistence – in the name of the Lord and on behalf of the king. According to a commentary on the “Siete Partidas,” the most important piece of legislation issued by the Spanish crown, the bishops were, under certain circumstances, permitted to dispense justice on worldly matters. “Citing the norms of the papal church of the middle ages, church representatives claimed jurisdiction over the indigenous population, who came under their protection in the same way as widows, orphans, the poor and the sick,” explains Duve.

RULES FOR PRICING AND FINANCIAL TRANSACTIONS

Clerics made the law – not just in provincial councils, but also through their booklets and manuals. “We suppose that this type of normative literature of theological provenance will have contributed decisively to the establishment of the structures of colonial dominance and the associated normative order and the constitution of spheres of law,” says Duve. In this way, a sphere of law arose in the New World that was based on Catholic Christian values and Old World values, and that refined them and quickly brought forth proper normative sources.

This may explain why Azpilcueta’s little handbook for confession was so popular. Ever in search of pragmatic literature, Otto Danwerth has made a detailed analysis: “It includes many topics that one would not expect in such a work.” There are norms covering various types of contract and reasonable prices. In his chapter on the 7th Commandment, “Thou shalt not steal,” Azpilcueta discusses questions of taxation and usury. Also aspects of marital, family and inheritance law can be found in the manual.


MANVAL
de confessores, y
penitentes, que clara y breuemẽte con
tiene la vniuersal, y particular decision
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Frãcisco dela puincia de la piedad, y despues visto
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tado por el mesmo Doctor en materias, sentẽcias,
alegaciones, y estilo, que puede parecer otro.
Con repertorio copioso de todas las materias al cabo.
Y con el de los capitulos al comienço.
Con priuilegio Apostolico para siete años.
Vendense en Coimbra a medio ducado
en papel. 1553.

Bestseller: The Manual for Confessors and Penitents written by Martín de Azpilcueta, an influential 16th century expert on canon law, was one of the most important sources of advice on day-to-day legal matters.

Azpilcueta’s strength lies in his ability to explain complex legal contexts in a simple, true-to-life manner. “Clearly structured and in understandable terms, he offered solutions to the acute problems of economic life and financial transactions in the New World – such as emerged after the discovery of important silver mines in Zacatecas in Mexico and Potosí in Upper Peru,” Danwerth explains. No wonder that many colonial representatives, from scribes to senior officials and from simple missionaries to bishops soon kept a copy on their shelves. In fact, Azpilcueta himself never set foot in America. But he gathered reports on the Spanish and Portuguese colonies from his students, acquaintances and his missionary nephew. >

Azpilcueta, however, wasn't the only one who knew how to pen comprehensible texts. Many writings, tracts and manuscripts appeared at that time, mostly aimed at bringing the faith to the indigenous "new Christians." The Franciscan Alonso de Molina, for example, who had learned Nahuatl, the language of the Aztecs, as a child on the streets of Mexico City, not only compiled the first dictionary to communicate with the indigenous population. He, too, wrote a handbook for confessors. De Molina, too, was writing for Spanish-speaking clerics, but he also offered them – and this is quite particular – translations into Nahuatl. And he included impressive illustrations that the priests could show to the Indians. Where language faltered, images assisted.

Carolin Behrmann of the Institute for Art History of the Max Planck Society in Florence analyzes the importance of images in and for the legal process in a broader frame. "The law in its entirety can't be communicated in words alone, it also requires objects, symbols and artifacts," explains the head of the research group "Nomos of Images. Manifestation and Iconology of Law." Together with an international group of PhD students, she investigates images that helped make manifest legal reasoning and practice from the late Middle Ages through to the 21st century.

Her research into image and symbol theory within Spanish late scholasticism of the 16th century considers the importance of image-based theology and addresses questions similar to those posed by the legal historians in Frankfurt. However, the timeframe of the "Nomos of Images" project is not restricted to the early modern era. Behrmann regards images associated with

Group Leader Carolin Behrmann and Felix Jäger, a PhD student on her team, inspect a selection of photographs from the collection of the Institute for Art History in Florence.

Photo: Institute for Art History, Florence – Max Planck Institute/Micaela Mau

» From the Middle Ages, a visual language established itself to express norms that the public could “read” – through allusion and allegory, without words.

A warning to judges: The 1338 fresco by Ambrogio Lorenzetti in Siena’s Palazzo Pubblico depicts Tyranny as the devil enthroned, surrounded by the vices avarice, arrogance and vanity.

Photo: Institute for Art History, Florence – Max Planck Institute

legal meaning as “visual constitutions” that are gaining momentum today. She is interested in their use in the course of history through to the present day – not least in order to heighten the general awareness of their legal associations: “There is a long tradition of using images to explain laws and prohibitions,” says the project leader.

Beyond the confines of time and culture, her group is studying how moral and normative connotations have been communicated. Their interests range from classical works of art such as depictions of the Last Judgment displayed in courtrooms to modest and less visible signs in the public sphere. For example, engravings on the walls of medieval houses often reflect the standard dimensions of bricks or goods and thus pictorialize commercial law.

PUNISHMENT MUST BE VISIBLE

Equally important is the analysis of the places where justice is acted out: “There is evidence of legal motifs in public buildings and courtrooms dating back to the 13th century,” says Carolin Behrmann. Biblical themes were popular. “The image of Doubting Thomas who laid his finger in Jesus’ wounds was a popular motif in civil courts,” explains the art historian, pointing to the “Mercanzia,” the court of the five great Florentine guilds. The visual appeal to every judge acting in that court was to come as close to the truth as possible! Biblical kings served as “exemplum iustitiae,” among them King Solomon, who appears in the courtroom of the Palazzo Comunale in Lucignano, Arezzo.

But also the downside of legal judgment and power were depicted. The walls of the Palazzo Pubblico in Siena confront images of ideal government with the image of tyranny: the frescoes by Ambrogio Lorenzetti dating from 1338 warn against bad judges and unjust dominion. Tyranny is represented as the devil enthroned, surrounded by the vices avarice, arrogance and vanity. On the other wall there are figurations of good governance with the virtues justice, courage, moderation and wisdom, in company with peace and magnanimity.

Another aspect of the Nomos project’s research is the advancement of knowledge of the law: Which were the evidentiary processes applied, and how were they supported by visual argument? Behrmann touches on the broad area of torture, the martyrdom of Christian saints, and not least the historic importance of the visibility of punishment that plays a significant role yet today.

Breaches of the law were often turned into a public spectacle. “Forms of public humiliation that shamed a person in a manner for all to see, in an undignified posture, embarrassing garments, disfiguring costume, with distorted facial features or bearing an insulting message, are among the reputation- and honor-based punishments imposed by pre-modern European criminal law,” explains Behrmann.

The forms and formats of humiliation varied widely from one era to another: rings and chains still remain attached to pillars and house fronts in busy squares as reminders of former pillories. Humiliation and deterrence might also be enforced by the crude iron mask of shame, or scold’s bridle, and the coat of shame, a barrel-like structure of wooden staves that the delinquent was forced to wear. Although highly controversial, shaming sanctions that depend on the public display

Mexico's national saint María de Guadalupe features some important Aztec elements, such as the blue mantle worn by the former indigenous ruling class. The downcast sickle moon at her feet represents the vanquished snake god Quetzalcoatl.

of the offender can still be found today, a formal judicial sanction in criminal law (for instance in the US).

In this way, the law established a visual language that the public could "read" – through allusion and allegory, without words. Subject, composition and arrangement were no accident in the 16th and 17th centuries, they were intentional. "In the early modern era we see a flood of laws passed and new codes of conduct derived from moral theology, which again had to find a universally comprehensible form," says Behrmann. And just as a plethora of legal epitomes and compilations of major legal works emerged at this time, so too the works of art of the Baroque provided a vivid clarity – in Europe and the New World.

Churches and administrative buildings in the New World were designed on the principle of *docere, delectare, movere* – they should teach, delight and move. Spanish painters travelled to the colonies to decorate the blank walls of buildings both sacred and secular. Splendor and opulence mattered, as an alternative to the richly bedecked Inca, Aztec and Mayan temples and cities. Visual imagery was harnessed in the form of detailed depictions of martyrdom and opulent images of the Virgin Mary, which were soon to acquire a style of their own.

Indigenous beliefs were skillfully integrated, a particularly good example being the depictions of Mexico's national saint, the Virgin of Guadalupe. This image of Mary is not only venerated in churches, but remains to this day ubiquitous in Mexican daily life. According to legend, in December 1531, Mary appeared to a Chichimecan baptized under the name Juan Diego, asking that a church should be built on the stones of a former Aztec temple dedicated to the mother goddess Tonantzin. The Bishop didn't believe him. Only when roses bloomed in mid-winter and he recognized the image of Mary on Juan Diego's coat did he have the church built, unleashing a wave of conversions that culminated in mass, as well as forced, baptisms. Did it really happen, or was it just successful PR by a bishop who sought to replace the colorful, polytheistic beliefs of the indigenous population with the Virgin Mary? Either is possible.

Art and legal historians are agreed that a mission powered by the sword alone wouldn't have brought about a permanent conversion to Christianity. "The Church at that time took on an important role as intermediary and translator in the transatlantic clash of civilizations," explains Thomas Duve, adding: "The Spanish and indigenous elites didn't live in isolation, they interacted." Franciscans and Jesuits studied the indigenous peoples' customs, traditions and concepts of law. And they were skilled at what experts term "cultural translation": the ability to integrate indigenous beliefs and contexts into the Catholic faith, not only in the interests of education, but also to afford the necessary scope for reinterpretation.

In this way clerics and artists whose names are scarcely known today influenced the reality of life in the New World at least to the same extent as the famed conquerors. Their handbooks and art works still stand as evidence. ◂

TO THE POINT

- **Catholic friars and priests played a major role in establishing Spanish dominion in South and Central America.**
- **In doing so, the clerics preferred condensed texts rather than the full official versions of laws.**
- **The Spanish legal system was transmitted alongside the Christian faith, with the Church skillfully integrating and reinterpreting indigenous traditions.**
- **Laws and prohibitions were also explained with the aid of imagery – in the New World as in Europe, using biblical scenes or symbolic depictions of vice and virtue.**

GLOSSARY

Allegory: The description of a subject in the guise of another subject. The portrayal of abstract characteristics in human form, such as the depiction of justice as a woman with her eyes blindfolded and holding a balance in her hand.

Epitome or breviary: An extract or simplified précis of a more extensive work.

Indigenous: Born in or native to a certain territory. The term is used, for example, in connection with peoples, languages and traditions.

Conquistadors: The Spanish conquerors of Central and South America in the 16th and 17th centuries.


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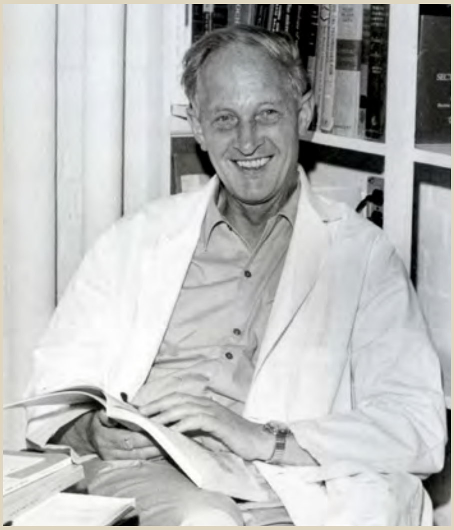
A Foul Enemy in Fowl

Flu viruses are highly mutable – and thus able to swap hosts. **Werner Schäfer** at the **Max Planck Institute for Virus Research** in Tübingen suspected as early as the mid-1950s that bird flu can also pose a threat to humans. Decades later, his suspicions were confirmed.

TEXT **ELKE MAIER**

The birds began to die in the spring of 1997. Within the span of a few days, 7,000 chickens on three poultry farms in Hong Kong perished. A short while later, a three-year-old boy who had been admitted to the hospital with flu symptoms died. Tests revealed that the same pathogen was the cause of death in both cases: a bird flu virus of the H5N1 type. After 18 more people were infected, six of whom died, experts became alarmed. Was a new flu pandemic imminent?

The incident brought to mind images from 1918/1919, when the Spanish flu claimed an estimated 50 million lives. To ward off the danger, more than 1.2 million chickens and hundreds of thousands of other birds were slaughtered in Hong Kong's poultry markets and on the surrounding farms. In time, the scare passed – but the concerns remained.


Bird flu as a research field: Werner Schäfer dedicated much of his scientific career to studying avian influenza.

The Hong Kong outbreak is the first documented case in which a bird flu virus not only infected humans, but also killed them. However, fears had been circulating for quite a while that this could happen one day. Virologist Werner Schäfer at the Max Planck Institute for Virus Research in Tübingen had already speculated about it in the 1950s.

Schäfer was born in Wanne, Germany on March 9, 1912. He originally wanted to become an architect and, after completing his secondary education, did an apprenticeship in carpentry. He later changed his mind and studied veterinary medicine in Giessen. After earning his doctorate, he joined the Veterinary Hygiene and Animal Infection Institute under Erich Traub, an expert in foot and mouth disease.

He then yielded to his thirst for adventure. In the summer of 1939 – shortly after marrying – he headed for East Africa on a grant from the German Research Council. In Tanzania, he set up a simple laboratory in a building on a German farm, where he began to carry out research into animal diseases such as anthrax, blackleg, brucellosis and pseudorabies, which were threatening the country's livestock.

Schäfer could well imagine a future as a researcher in Africa, but his plans were thwarted by the war. He was incarcerated and deported to Germany in 1940, where he was drafted into the army as a veterinary officer. For a while he was based on the island of Riems, near Greifswald, to work at the Reich Research Institute there in a program aimed at developing vaccines against influenza, rinderpest and bird flu.

After the war, there were no immediate prospects for a post as a virologist. Without further ado, Werner Schäfer opened a veterinary practice in Usseln, Hesse. Business flourished, and he had no concerns about his family's subsistence. Nevertheless, he didn't hesitate for a moment when Nobel laureate Adolf Butenandt, then Director of the Kaiser Wilhelm Institute for Biochemistry in Tübingen, looked him up in the spring of 1948 and offered him a research post. After three years as a rural veterinarian, the 36-year-old moved to Tübingen to head the Animal Virology Department.

The research team was initially housed in a ramshackle outbuilding of the Pharmacology Department. The annual budget for equipment was a mere 10,000 marks. Despite this, Werner Schäfer was inordinately productive; he had learned how to improvise in Africa. His career soon took off. In 1954 he was elected a Scientific Member of the Max Planck Society. Two years later, he was appointed Director of the Biological and Medical Department of the newly created Max Planck Institute for Virus Research in Tübingen.

One of Schäfer's main research interests was the virus responsible for avian influenza, now commonly known as bird flu. The highly infectious pathogen affects birds in the wild as well as poultry of all kinds. Infection leads to dyspnea, apathy, high fever and motor disorders. Infected animals usually die within a few days.

The dreaded virus offered a number of advantages as a study object: It proved to be an excellent model for studying enveloped viruses. Moreover, public health policy forbade US competitors

Photo: MPG

Epidemic source: Close contact between birds and humans favors the emergence of new influenza pathogens.

from working with the pathogen. The virus is easy to handle in the laboratory and multiplies vigorously in incubated chicken eggs. Heinz Schwarz, an electron microscopist who worked closely with Werner Schäfer at the Institute, recalls: "Some of our colleagues periodically drove in the Institute's car, an Opel P4 dubbed Friedolin, to a chicken farm in Tuttlingen to pick up pallets of eggs."

Soon they were cultivating viruses at full speed. Schäfer's aim was to find out the functions of the various viral components and to determine the role they play in infections. To this end, he combined electron microscopic structural analyses with physicochemical and immunological investigations and observed the course of the disease in experimental animals.

"Schäfer was a true pioneer, since there was no DNA sequencing at the time," says Volker Moennig, veterinary professor at the University of Veterinary Medicine Hannover, Foundation who had

Die Welt, November 5, 1991

» It was Schäfer who surmised – correctly – that certain bird viruses could act as an inexhaustible reservoir for the emergence of new influenza variants.

earlier worked at the Institute in Tübingen. "The times were also different with regard to handling the virus. Today, a laboratory safety rating of 3 would be mandatory."

Despite the limited resources, Schäfer managed to characterize the bird flu virus in detail. He noted an astonishing similarity to another pathogen – the causative agent of influenza A in humans. Under the electron microscope, both appeared to be studded with fine spikes, which Schäfer compared to the "detonators of a naval mine." The viruses also shared many physicochemical and immunological properties. For example, both pathogens were able to infect mice, causing a pneumonia that proved fatal after a few days. The pathological changes in lung tissue caused by both forms looked identical. Schäfer even managed to immunize mice against influenza A with the bird flu virus and vice versa.

The striking similarity of the two pathogens led Werner Schäfer to a troubling conclusion: "It is conceivable that representatives of this group occasionally change their host specificity so that a new type of influenza virus […] emerges," he wrote in a seminal work in 1955. He was to be proven right.

Today we know that avian viruses do, in fact, act as a natural gene pool from which new flu viruses can emerge that can potentially infect humans. A tiny change to a protein building block is enough to enable the virus to evade the immune system and change its host. The danger is especially acute in places where people and poultry live in close proximity, as in many Asian countries.

Experts particularly fear the emergence of hybrid viruses: when a bird virus and a human virus come together in an infected cell, they are able to exchange DNA segments to form a new virus that spreads from human to human – a recipe for a pandemic. The Spanish flu may have been the result of such dangerous liaisons. In the 1997 Hong Kong flu epidemic, the viruses made the leap from bird to human, but fortunately not from human to human.

Werner Schäfer presented his findings on viral kinship at a symposium in London in 1956. Luminaries including James Watson and Francis Crick, who had discovered the structure of DNA three years earlier, were in the audience. It proved to be an international breakthrough for Schäfer. There followed invitations from all over the world, and the "Tübingen Group" ranked among the most pre-eminent virus researchers in the world.

Werner Schäfer devoted 16 years of research to the avian flu virus. Thanks to his work, the pathogens have long ranked among the best characterized of all animal viruses. Schäfer also laid the groundwork for the development of vaccines when he discovered that a component of the viral envelope is sufficient to confer immunity in a host. This led to the development of split-virus vaccines, which are still used today in some flu and hepatitis B vaccines.

Schäfer finally closed the bird flu chapter of his career in the early 1960s. At over 50, he switched to an entirely new research field: retroviruses, which were thought to play a role in the development of cancer. In fact, oncogenes, which promote unbridled cell growth, were discovered for the first time in the genomes of retroviruses. Schäfer and his team investigated the role of the viruses in the development of leukemia and carried out successful immunization experiments.

In the 1980s, retroviruses made headlines when it was discovered that they cause AIDS. By that time, Schäfer had already retired. The winner of many awards, he died in Tübingen on April 25, 2000 at the age of 88.

Photo: Yusuf Ahmad/Reuters

PhDnet Prioritizes Communication and Equal Opportunities

Max Planck Society's student platform elects new management board

For several years now, a handful of PhD students at various MPG locations have met regularly for their weekly video conference. Now PhDnet has elected a new managing board for 2017, so a new team is lining up for an online meet.

"We are particularly keen this year to focus on topics that can add further strength to the Max Planck doctoral student community, such as improved communication and equal opportunities," stated the new Board, summing up their program for 2017. "Our predecessors have done a tremendous job over the last three years, particularly regarding the new PhDnet statutes, which bring democratic legitimacy to the status of representatives at MPG by setting a minimum turnout in elections at each MPI. Our task will be to ensure that this is applied in practice, and the procedure continuously improved."

"There is still much to be done in terms of communicating PhDnet events and activities," says Lisa Scheuermann. "But we also intend to make our voice heard in the area of scientific communication – with the new Offspring magazine and our own blog."

"There is no room for activities without the proper data," adds Spokesperson Leo Borchert – "so our team is planning a survey in the spring that will show us which topics PhDnet should be prioritizing in the coming years. Vacation time, for instance, remains a hot topic that we are keen to address at our handover meeting in Munich."

The PhDnet board: Spokesperson Leonard Borchert (third from right), Secretary General Rafael Laso Pérez (right), Treasurer Gabriel Guerrero (second from left) and Section Representatives Jana Lasser (CPTS), Lisa Scheuermann (BMS) and Teresa Hollerbach (HS, left to right).

According to Jana Lasser, "Vacation time is also an equal opportunities issue. It isn't easy to satisfy the needs of international doctoral students and families with just 20 days of vacation per year." To heighten the general appreciation of equal opportunities, PhDnet intends to campaign for more individual working conditions that give fair consideration to all lifestyles, as well as organize seminars on diversity management.

Photo: Private collection

ERC Funding Times Seven

Max Planck researchers receive sought-after funding boosts

In the contest for the Consolidator Grants awarded by the European Research Council (ERC), one female and six male scientists from among MPG's ranks have each been granted up to two million euros in funding. The MPG was Germany's most successful institution in this fourth round of applications under the EU's "Horizon 2020" research framework programme, ahead of the Helmholtz Association (six grants), the University of Heidelberg (five) and the Technical University of Munich (three). The ERC received a total of around 2,300 applications and awarded 314 Consolidator Grants. The Consolidator Grants, which are awarded annually, are aimed at scientists who received their doctorates at least seven and at most 12 years prior and who wish to implement their project at a European scientific institution.

THE ERC GRANTEES

Simon Alberti, MPI for Molecular Cell Biology and Genetics; Thomas Barends, MPI for Medical Research; Stephan Gruber, MPI of Biochemistry; Naoko Mizuno, MPI of Biochemistry; Steffen Klamt, MPI for the Dynamics of Complex Technical Systems; Pietro Omodeo, MPI for the History of Science (will be doing research with his ERC grant at the University of Barcelona); and Glenn van de Ven, MPI for Astronomy

Symposium in the Age of Brexit

Researchers at Britain's University of Cambridge and the MPG met recently at the Harnack House to explore the possibilities for intensifying collaboration in the neurosciences

It was purely by chance, but symbolic nonetheless: scientists from the MPG and the University of Cambridge assembled in Berlin for a "matchmaking" symposium to consolidate their collaboration on specific projects on the very day on which the House of Commons confirmed that the UK would declare its intention to exit the EU. "In view of the growing uncertainty at the European and global level, this conference cannot simply be regarded as business as usual," said MPG Vice President Bill Hansson. "It is an important signal of a desire for continued cooperation with our British partners."

The centerpiece of the two-day symposium in early February comprised nine dual presentations, each delivered by a pair of expert neuroscientists from Cambridge and the MPG. Six MPIs were represented, predominantly by Group Leaders. Participants and organizers alike deemed the event a success: in addition to the ongoing development of existing collaborations, the coordination itself nurtured a productive dynamic environment for new initiatives. Going forward, the "matchmaking" symposium format could serve to close the gaps that might be left if Brexit were to spell the end of established mechanisms for scientific cooperation.

Award for Going the Extra Mile

Two Administrative Headquarters staff members honored for their outstanding commitment

The MPG awards the Communitas Prize for particular commitment to our scientific organization. As President Stratmann has emphasized, the award is independent of hierarchies, and this year it goes to two members of staff at Administrative Headquarters. He also encouraged Directors to nominate dedicated colleagues at their institutes.

Both prizewinners work at the Max Planck House in Munich and were themselves – as is commonly the case at HQ – formerly active scientists, which may well be why they are so "hands on." Verena Mauch is one of a team of just under 20 "IL-ers" in the Institute Liaison department, the first, personal point of contact for MPIs wishing to address overarching administrative inquiries to Headquarters. Organized by Sections, each "IL-er" is responsible for certain individual institutes that in effect become "their" MPIs – in Verena Mauch's case, those are the MPIs for Biological Cybernetics, Molecular Cell Biology and Genetics, and Psychiatry.

Award ceremony at the Scientific Council meeting: President Stratmann with the prizewinners, Verena Mauch and Christiane Walch-Solimena (right).

"PERFORMANCE BEYOND ALL EXPECTATIONS"

Verena joined the MPG while studying for a doctorate at the Radboud University after a period of employment in The Hague. As MPG President Martin Stratmann explained when the awards were presented at the Scientific Council meeting in late February, she receives the prize for her "performance beyond all expectations," both in day-to-day business, such as preparing appointment interviews, and in responding to crisis situations, such as the recent campaigns by animal rights activists.

The second prizewinner was Christiane Walch-Solimena, who holds a doctorate in biochemistry and was formerly a researcher at two MPIs, the Howard Hughes Medical Institute and Yale University, and who worked as a Group Leader at the MPI for Molecular Cell Biology and Genetics before moving to Headquarters. Since 2009 she has been the Scientific Assistant to the President for life sciences and medicine. In this capacity, she also assumed responsibility for coordinating the "discussion year on animal studies" initiated by President Stratmann.

Christiane Walch-Solimena met this enormous challenge with "genuine devotion, patience and empathy," as the President explained – for instance in integrating a wide variety of experts including scientists, animal facility managers, lawyers, IT experts and communications specialists. She was also instrumental in helping prepare content for the policy paper on animal studies in basic research that was successfully presented to the Senate in late 2016.

Photo: Amac Garbe

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Content Authority
Dr. Christina Beck (-1276)

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Editorial Staff
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Photo Editor
Susanne Schauer (-1562)

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 Koch
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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