

Max Planck RESEARCH



The Science Magazine of the Max Planck Society 4.2016



Sleep

RESEARCH POLICY
Rebooting
Open Access

ROBOTICS
Microboats
to the Rescue

ATMOSPHERIC CHEMISTRY
Hot Air
in the Orient

SOCIAL ANTHROPOLOGY
An Ocean
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Photo: M. Kalbe, MPI for Evolutionary Biology, Plön

The Lab in the Big Lake

Sunshine, water, blue skies and a castle in the background – many people associate the lakes in and around Plön, in northern Germany, with carefree vacation days. The scientists at the Max Planck Institute for Evolutionary Biology have certainly not lost sight of the beauty of the landscape, but the main focus of their interest is one of the lakes' inhabitants and its genes. The three-spined stickleback (*Gasterosteus aculeatus*) feels very much at home along the shores of Great Plön Lake. And right here, amid the natural nesting grounds of these small fish, is where the Institute's open water research labs are located.

In six large cages, the sticklebacks – bred in a lab and released into the lake in the spring – are able to claim territories in natural environments, build nests and reproduce, while at the same time being exposed to the parasites that are found there. What makes these fish special is that the specific individual combination of immune genes of every single animal is known. This enables the researchers to observe which sticklebacks are the most resilient in the never-ending competition with the parasites and – as father and mother are determined for every single egg with the help of molecular genetic methods throughout the entire breeding season – how many progeny each fish has.

The most resistant fish pass on their immunocompetence to their numerous offspring. It appears that female sticklebacks prefer mating partners whose immune genes best complement their own – and that, through their healthy coloration, prove that they possess the necessary genotypes against the currently prevalent parasites. The mother's choice of partner thus has a direct advantage for her young.

The females identify which male is worth considering for mating not only by coloration, but also by the odor of the potential partner, because odor is determined – just as in humans, incidentally – by the composition of the immune genes.



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Ludwig II of Bavaria conducted his government business at night and slept during the day. Did the Fairy Tale King have a disorder that disrupted his sleep-wake rhythm? Even Gregor Eichele can only speculate, but he and his team at the Max Planck Institute for Biophysical Chemistry have gained much new insight into the body's natural timekeepers.

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People who haven't gotten enough sleep often see the world as a fairly sad place. If their tiredness lasts for weeks or even months, their dark mood may become chronic and develop into depression. Conversely, depression is frequently also associated with severe sleep disorders. Axel Steiger and his team at the Max Planck Institute of Psychiatry in Munich are studying the connection between disturbed sleep and depression.

ON THE COVER Sleep is a basic need and is vital to such functions as learning and remembering. Internal clocks in the body control the day-night rhythm and influence the need for rest – both in humans and in many animals.

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Under the Open Sky

“Images of Science” now also in Bremen




In front of “Universum Bremen,” the Hanseatic city’s science museum, visitors are treated to an impression of the research conducted at Max Planck Institutes.

No doubt about it – few things are more likely to attract attention than spectacular images. The exhibition “Im-

ages of Science” exploits this phenomenon. With surprising, aesthetic pictures in a large format, it offers unusual,

easy access to the research conducted at Max Planck Institutes. The exhibition comprises a total of 50 motifs that are regularly updated and supplemented by new ones. The images can be viewed in their entirety online at any time, as well as in changing compilations in various locations around the world. In Germany, too, “Images of Science” continues to enjoy great popularity. Every year, the exhibition in Munich attracts more than one and a half thousand visitors on a single evening during the “Long Night of the Museums” event. The latest addition consists of an open-air show. High up in the north of Germany, visitors have been treated to ten pictures outside the “Universum Bremen” Science Center since July. Visitors who like the pictures can use the QR code to instantly log onto the online exhibition on the Max Planck Society’s website.

 www.images.mpg.de

The Senses of Life

Martin Wikelski and Bonnie Bassler presented with Max Planck Research Award

The question of how organisms perceive their environment is the focus of this year’s Max Planck Research Award. Yet the two prizewinners are studying living organisms that couldn’t be more different: while Martin Wikelski, Director at the Max Planck Institute for Ornithology, observes the sensory powers of animals in their natural habitat, Bonnie L. Bassler from Princeton University and the Howard Hughes Medical Institute works with bacteria. The American played a decisive part in the discovery that even the smallest creatures communicate with each other via signaling substances and then act collectively. Martin Wikelski is exploring the question of how different vertebrates perceive their environment and adapt to it. Above all, he has gained valuable insight into how animals navigate and find their destination on trips that sometimes cover thousands



Bonnie Bassler and Martin Wikelski investigate how different creatures perceive their environment.

of kilometers. Using the satellite-based observation system Icarus, he is a pioneer in the field of wild animal telemetry. The Max Planck Research Award, which is endowed with 750,000 euros, is funded by the German Federal Ministry of Education and Research and bestowed by the Alexander von Humboldt Foundation and the Max Planck Society.

“Actually, we would have liked to carry on!”

Holger Sierks from the Max Planck Institute for Solar System Research on the end of the Rosetta mission

The space probe Rosetta landed on the surface of the comet 67P/Churyumov-Gerasimenko on September 30, bringing to an end one of the most exciting projects in the history of European space exploration. Holger Sierks from the Max Planck Institute for Solar System Research in Göttingen managed the consortium for the Osiris camera system to which the science world and the public owe a debt of gratitude for the spectacular images of the comet's core.

Mr. Sierks, the Rosetta cometary mission has come to an end. Doesn't this make you feel a little sad?

Holger Sierks: The mission lasted around 30 years: starting with the orientation phase at the scientific level, then the planning and construction phase, and finally the travel time to the target comet. During the past two and a half years, Rosetta has accompanied the comet at a close distance. The end was very emotional for everyone involved. Only a very small number of colleagues remain from the pioneering phase; I myself came on board 20 years ago. Rosetta is thus a good example of intergenerational work in space research. What's more, the space probe still functioned perfectly right up to the end. Actually, we would have liked to carry on!

But would that have been possible?

The alternative would have been to put the probe into hibernation again and to reactivate it after the comet had reached its furthest point away from the Sun. But then the fuel wouldn't have been sufficient for the comet to re-approach the Sun and observe the next cycle of activity. That's why we decided to land the space probe on the comet now.

What was the most interesting aspect of the mission for you personally?

I was moved most by the discussion about the origin of the comet. We hope to gain some insight into what the solar system looked like during the first few million years. The cometary nucleus we see today is thought to have formed from two smaller ones. In the gas phase of the accretion disk around the young Sun, these nuclei



“The end was very emotional for everyone involved”: Holger Sierks, scientist at the Max Planck Institute for Solar System Research

decelerated and collided with each other at very low speed.

What I also found exciting are the cylindrical sinkholes, where we look down from the surface almost 200 meters into the inner structure of the comet – and that on a cometary nucleus with a radius of just 1,000 or 2,000 meters! Although the material there has certainly been processed somewhat by solar radiation, we look into the depths of the comet and thus perhaps back into its 4.5-billion-year history. And the inner walls of these sinkholes aren't smooth and homogeneous – they have very sharply defined structures on the scale of two to three meters resembling oranges in a crate.

So there is still a lot of data waiting to be evaluated. How long do you think you and your colleagues will be busy with that?

Collaborations from the Giotto mission that flew past Halley's comet 30 years ago are still ongoing today. I assume that we'll need 20 or 30 years for Rosetta, as well. What I mean here is not just the analysis of the Osiris image data, but also the global analysis of the spectrometer data, the thermal, millimeter and sub-millimeter data on the near-surface structures from Miro and the other instruments aboard


the space probe. As far as the Osiris images are concerned, we initially have three years to compile a comprehensive archive. This procedure is new in the research community and also for the European Space Agency. This work is normally completed when the data is handed over after 12 months. We will calibrate the images, develop mosaics and terrain models and then make the products available to the public and the scientific community.

Your bottom line at the end of the mission?

In 2014, Rosetta managed to appear on the front cover of *SCIENCE* with the caption “Breakthrough of the Year.” I believe the mission must indeed be classified as a breakthrough in cometary research.

What is the next step in cometary research after Rosetta?

I think the scientific community agrees that the next step has to be to bring cometary material to Earth and analyze it in laboratories here – especially the organic components. We are already considering how we would design such a sample-return mission. Interview: Felicitas Mokler


 Dossier on the subject:
www.mpg.de/8310003/rosetta_mission

Understanding Animal Research

Alliance of scientific organizations launches information initiative

The subject of animal research frequently stirs strong emotions, but many areas of basic research simply can't do without examinations using animals. They are the only way to understand complex processes in organisms; they are the starting point for new scientific insights and the drivers of progress in medicine. Against this background, the Alliance of Science Organisations in Germany, of which the Max Planck Society is also a member, has launched its "*Tierversuche verstehen*" (Understanding Animal Research) initiative. The aim is to provide the public and the media with comprehensive, up-to-date facts on animal research. The most important building block in this process is an internet platform that will provide news

and background articles, films, infographics and an image database, as well as offering an opportunity for discussion. Journalists will be able to establish contact with experts, and schoolchildren and teachers can find information for their lessons. The objective is to make the debate on the necessity and benefits of animal research and the alternatives to it more objective. The initiative is also actively engaged in social media. Starting at the end of this year, "*Tierversuche verstehen*" also plans to host presentations and discussion forums at public events.

 www.tierversuche-verstehen.de
(available only in German)



Well Founded

Max Planck Foundation celebrates its anniversary

The Max Planck Foundation, an independent institution, has been supporting the work of Max Planck scientists for ten years. In that time, the income from the Foundation capital has provided more than 45 million euros in funding for around 30 projects, such as the second flight of Sunrise, the largest flying solar telescope, and the initiative behind the Center for Systems Biology in Dresden. The additional private funds offer fast, flexible leeway where public funds are not available. A further focus of the support consists in securing the working conditions for outstanding researchers, particularly for recruiting them to a Max Planck Institute or retaining them there.

Photo: TVVde



MAX-PLANCK-GESellschaft

Thank you.

10 years of facilitating ideas
10 years of outstanding commitment
10 years of Max Planck Foundation

For ten years now, the Max Planck Foundation has been encouraging and funding our knowledge pioneers to explore frontiers in science. We would like to express our heartfelt thanks to all our contributors and supporters, in particular the founders Stefan von Holtzbrinck and Reinhard Pöllath.



Martin Stratmann, President of the Max Planck Society



www.maxplanckfoundation.org

Double Career Launch

The Max Planck Society and the Technical University of Munich (TUM) jointly appoint top young scientists

The opportunity to pursue one's own research ideas, gain access to first-rate lab equipment and exchange ideas with experienced colleagues across disciplines: these are the characterizing features of the new collaboration model between the Max Planck Society and the Technical University of Munich (TUM). The concept: Young scientists who were selected from an international pool of applicants to lead a Max Planck Research Group receive an additional appointment to a fixed-term tenure track professorship from the TUM. This gives the young scientists reliable prospects for their future career development. An evaluation after six years determines whether they will research and teach at TUM on a permanent basis – initially as an Associate Professor with a W3 salary and linked to an option for further promotion to Full Professor. According to Max Planck President Martin Stratmann, the offer is the only one of its kind in the world: “The new collaboration is a real win for Germany as a science location in the global competition for outstanding junior scientists.” The two institutions jointly appointed their first seven junior talents in October, some from such renowned institutions as the University of California, Berkeley.



Common objective: Wolfgang Herrmann, President of the Technical University of Munich, and Max Planck President Martin Stratmann (right) anticipate that this collaboration will help them recruit the best young talent.

On the Net



Coral Reefs in Time Lapse

Corals are among the most colorful inhabitants of the sea. These cnidarians are found not only in tropical waters bathed in light, but also at depths of over 2,000 meters below sea level. A four-minute video consisting of more than 25,000 macro images shows the corals' shimmering beauty. The images were taken at the Great Barrier Reef off the coast of Australia and document one of the greatest natural wonders of our Earth. This sensitive ecosystem is in extreme peril as a result of global warming and ocean acidification, but also due to tourism and the planned expansion of a coal port.
vimeo.com/156942975

Worth Talking About

Telling stories, explaining, discussing, persuading, teaching – what people achieve with language goes far beyond the mere exchange of information. Without language, there would be neither trade nor politics, neither religion nor science, neither rights nor poetry. But the phenomenon of language contains many puzzles. To what do we owe this unique human capability? How do children learn to speak? And what characteristics has language developed in different parts of the world? A new dossier with interviews, videos and podcasts provides an overview of important research questions within the Max Planck Institutes.
www.mpg.de/language-research

Focus on Equal Opportunity

Talent, creativity and passion – these are the qualities the Max Planck Society banks on. The Society supports employees regardless of their gender, nationality, religion, disability, age, cultural origin or sexual orientation: the basis for successful research lies in diversity. To further reinforce this diversity, the Max Planck Society offers various forms of assistance that are concisely presented on its career website. The reconciliation of family life, leisure and work, the advancement of female scientists with the aim of enabling greater numbers of them to take up management positions, and mentoring and career development are all important pillars in this strategy.
www.mpg.de/equal_opportunities

Rebooting Open Access

The publishing world has changed dramatically with the relentless progress of the internet, but publishers continue to bank on strategies from the age of print. We present a case for the necessary transformation of the scholarly journals' business model – and an outline of the path to get there.

TEXT **RALF SCHIMMER**

For well over ten years there has been a demand for free access to the outputs of scholarly work, with open access (OA) being the focus of an approach that stands, full of promise, in complete contrast to the prevailing model. Despite this demand for open access, only about 15 percent of scholarly articles per year

of transforming the publishing industry's business model, which – despite the demand for OA – is still based on subscriptions.

Today it is almost impossible to imagine doing academic work without the opportunities the internet offers. Publishing environments already utilize digital technologies to support every aspect of the production process, from manuscript preparation to submission and peer review, and in almost all cases, publications appear in electronic form regardless of whether there is a parallel printed version. But at that crucial moment of the finished product's distribution, the digital process is fatally disrupted. Rather than being exhaustively promoted through the extensive real-time distribution possibilities that are an inherent feature of the internet, the laboriously created and quality-controlled publication is managed according to a philosophy of scarcity that, from a 21st-century perspective, can only be described as artificial. Publishers go to great technical and legal lengths to place content behind paywalls and eliminate opportunities for unrestricted access. >

Only 15 percent of scholarly articles per year are currently available through open access

are currently available in this format. Proponents of OA are therefore now beginning to wonder whether the initiative's strategic direction needs to be reconsidered: whether open access needs a reboot, so to speak, to achieve the very concrete goal



Graphic: Dorothea Pluta

This scarcity is caused by the remarkably tenacious conventions of the subscription system – by entrenched policies and procedures that were established between publishers and libraries over the course of many decades and that restrict access to the content of a scholarly journal to those readers whose library has acquired a subscription. This basis of exchange, to which both libraries and publishers readily accede, has remained surprisingly unaffected by the modernizing pressures of digitization. Hardly any other area of scholarly communication has escaped change to this extent, which is all the more perplexing given both the overall importance of journals to scholarship and the substantial amount of money involved.

The concept of scholarly journals dates back 350 years to a period in which the compilation of scientific papers and particularly their distribution presented significant challenges; these two dimensions governed access. This centuries-old production challenge has defined the approach to scholarly com-

At the national level, too,
various initiatives have articulated
increasingly ambitious goals

munication up to the beginning of the 21st century. Although this physical distribution challenge has been eliminated in today's internet environment, the subscription-based distribution and financing model persists, along with its inherent scarcity effects. It is beginning to dawn on the scientific community that the subscription system itself is the most significant barrier to open access, and that it will be necessary to tackle this problem if OA's breakthrough is to be achieved on a larger scale.

Free – in the sense of unrestricted – access to the results of scholarly work through the removal

of all the barriers that exist is, in principle, the central objective of every open access initiative. As the initiator of the 2003 *Berlin Declaration on Open Access to Knowledge in the Sciences and Humanities* and co-host of twelve Berlin Conferences so far, the Max Planck Society has always been at the center of the debate and is recognized the world over as one of the driving forces behind the movement. Together with a steadily growing number of scholarly institutions in many countries, the Max Planck Society is involved in projects, alliances and pilot enterprises to advance the principle of open access. After a decade of international development work, open access is now firmly established in scientific policy discourse all over the world. It is significant that the Global Research Council, established in 2012, immediately devoted attention to this topic, devising a corresponding resolution within a year of the Council's foundation. At the national level, too, predominantly in Europe, various initiatives have articulated increasingly ambitious goals. In the first half of 2016, these developments were adopted at the European level under the Dutch EU Council Presidency as the *Amsterdam Call for Action on Open Science*.

There is a striking gap between the widespread embedding of open access as an objective in scientific policy-making and the rather sobering fact that, despite all this support, only 15 percent of scholarly papers per year are published as open access. Perhaps even more significantly, this OA proportion – which is currently increasing by about one percentage point per year – does not by itself exert any transformative pressure on the subscription system. So far, there has been no sign of any shift in the prevailing distribution and financing arrangements, nor any attenuation of the relentless cost pressure on libraries as a result of the annual price increases demanded of them year after year by a monopolistic journal publishing industry. Despite the many achievements of open access to date, the traditional subscription system for academic journals continues to prevail. Indeed, it is thriving: the return



on sales of the big commercial publishers continues to rise, with margins ranging between 30 and 40 percent. There is much more money to be made in publishing scholarly information than in the automobile or oil industries; only Google and Apple are similarly profitable.

Proponents of open access are increasingly realizing that, while all the measures of the past ten years have certainly been useful – as seen in the adoption of requirements and mandates, the set-up of institutional repositories as instruments of the “green road” of secondary publication, and the countless recommendations and other documents supporting a broad advocacy strategy – a new strategy is nevertheless needed to establish open access on a grand scale. The measures implemented during the past ten years have been excessively focused on adjusting scientific practices to a particular notion of open access. It had been envisioned that scholars would have to move toward open access, so the governing idea was to steer their behaviors in a certain direction. Perhaps it is time to reverse that focus and move in the opposite direction. Rather than putting the onus on scholars to have to act in the spirit of OA, an alternative approach would be to embed this functionality anywhere it concerns them in their day-to-day work.

It is crucial that open access include the familiar and established journals that offer a perceived level of quality and certain career opportunities. If a scholar is attracted by a journal’s reputation and wants to publish there, we should surely not view the scholar’s stance as an obstacle, but rather the journal’s expensive and restrictive business model.

Establishing OA as the standard for scholarly communication requires that the corpus of scholarly journals – currently distributed through the subscription model and withheld from free use behind a paywall – be shifted to an open access business model on a large scale. The transition of existing journals is the ultimate and crucial goal of the transformation of publishing to open access: the payment streams that have traditionally been directed

toward financing journal subscriptions, and hence read-only access, should be redirected toward the immediate payment of publishers’ publication services. For more than a decade, such pioneering publishers as Biomed Central and PLOS have been demonstrating how OA-conforming business models can be developed and managed. Many publish-

Despite the many achievements of open access to date, the traditional subscription system continues to prevail

ers have followed their example, which is based on publication fees – so-called article processing charges (APCs). However, the practice of open access publishing also embraces other successful financing models that shouldn’t be overlooked.

Many individuals and organizations are involved in advancing the debate about the transition to OA and the eventual elimination of the subscription system, not least of which is the Max Planck Society. In April 2015, the Max Planck Digital Library (MPDL) published a white paper (<http://dx.doi.org/10.17617/1.3>) that established the fundamental feasibility of a large-scale transition to open access based on a careful analysis of both publication data and academic publishers’ sales figures. Market analyses show that academic publishers generate annual revenues on the order of 7.6 billion euros from global journal subscription sales. According to relevant publication databases such as the Web of Science, around 1.5 million articles are published annually in journals with an international reach. Doing the math, we arrive at a figure of about 5,000 euros being paid for every single article under the current subscription system; this is a substantial



sum that far exceeds the costs we have seen to date in the purely OA publication market. The declared costs in that market segment currently yield an average price of 1,300 euros for German universities. Even assuming that publication numbers and average prices will ultimately be higher, all the available evidence suggests that converting the subscription model to OA would be feasible within the limits of the financial resources that are already being deployed, without additional costs. In short, it is clear that there is already enough money in the publishing system to transition to OA.

Since its release in the spring of 2015, the MPDL white paper has become a central reference document for the global transition debate. The interest it stimulated was apparent at Berlin 12, a two-day international conference in late 2015 at which 100 representatives from 19 countries accepted the Max Planck Society's invitation to discuss an accelerated path to open access. There was general agreement at the meeting that the participants should collectively work toward the transformation along the lines of the arguments presented in this paper. The outputs of the conference, an Expression of Interest and a Roadmap action plan, were released in March 2016 as part of the Open Access 2020 campaign. Since then, there has been a steady increase in the number of scholarly organizations that have committed themselves to this campaign by signing the Expression of Interest. At the same time, increasing numbers of individual organizations and associations are recognizing that the subscription system is well past its expiration date, and that the financial flows need to be adjusted in order to effectively reform a system in which the substantial current spend produces levels of accessibility that appear meagre and intolerably restricted in the 21st century's digital world. It is becoming increasingly clear that a vastly superior system of scholarly communication could be developed and financed at no greater level of investment than the current system requires.

What needs to happen to bring about the desired transformation? The key to success is in the hands

of those institutions that administer the funds and decide where to allocate them and where not to; namely, the academic institutions, represented in this matter by their libraries. A substantial part of the campaign for change must therefore be directed toward libraries and their umbrella organizations. Now that the financial viability of OA has been demonstrated, a planned transition of the basis of payment from subscriptions to publishing services will involve applying new parameters and de-

In Germany, the Max Planck Digital Library has been actively working on transition models

veloping new process workflows. Libraries will need to gather much more accurate information than they have in the past about the volume of publications and their distribution among the various publishers, so as to develop transition scenarios and cost models, and on this basis establish target-oriented transition models with publishers. Such transition approaches have been steadily spreading for about two years, and are the furthest advanced in the UK, the Netherlands and Austria. In Germany, the MPDL has been actively working on transition models, and has been involved in a pilot project with Springer since late 2015. Other institutions have been following this lead, with the result that new announcements and contracts can be expected very soon.

A new contract model – described in professional circles as “offsetting” – has been established to support the transition; it provides a good entry point for a systematic redeployment of licensing costs (subscriptions) as publication costs. This approach attempts to release the stranglehold of subscriptions by demanding additional open access services based on current sales volumes. In this mod-

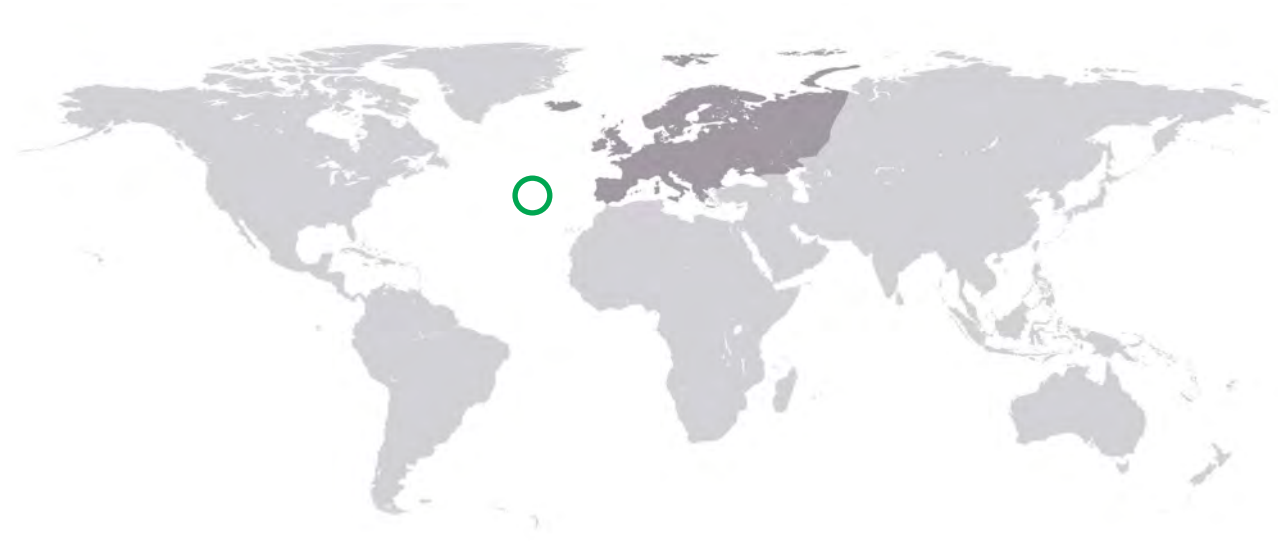
el, the library remains a subscription customer, continues to receive the required access rights, and secures for its patrons the right to publish in open access – all of which should ideally be achieved within the range of the current spending level. Offsetting's wider aim is a system change; it is a transition model, since it is not only the contracts' basic rationale that must be changed in the spirit of open access, but also the underlying financial flows and related accounting processes.

Academic organizations are using such transition models to offer publishers the opportunity for an orderly transformation. Although the targets of the transformation are the business model and the basis of payment to publishers, the aim is nonetheless to preserve publishing services as such and ensure that they continue to be remunerated fairly and appropriately. The disruptive element of the transformation is directed only at the financial flows, not at the exchange relationships between researchers and publishers overall. Research and publishing can unite in a large-scale transformation of these old-fashioned business models to put an end to the current artificial scarcity of academic content and create an environment that is geared toward maximum distribution, thus satisfying the legitimate expectations of today's digitally enabled world. At a time when information can be tweeted around the globe in seconds, the existing mode of scholarly communication seems absurd. If the orderly transformation of academic publishing is not achieved within the next few years, it won't be long before the next generation simply pulls the plug on it. ◀



THE AUTHOR

Ralf Schimmer, born in 1962, is Head of the Information Division and Deputy Head of the Max Planck Digital Library in Munich. A Doctor of Social Science, he is responsible for the centralized provision of electronic information to all Max Planck Institutes and has been involved in the Max Planck Society's open access objectives since the Berlin Declaration of 2003. Schimmer is a member of the advisory boards of various information facilities, EU projects and scientific publishers. He is currently Project Manager of the Open Access 2020 initiative and a member of the Steering Committee of the Priority Initiative "Digital Information" of the Alliance of Science Organisations in Germany.



Climate, Wind and Waves

Max Planck scientists cooperate with partners in around 120 countries worldwide, exchanging samples and data, and combining their expertise.

Geologist Ralf Schiebel from the Max Planck Institute for Chemistry in Mainz reports on his most recent paleoceanographic expedition in the North Atlantic, life on board the research vessel, and the joy of roaring ocean spray.

For the umpteenth time, I roll against the wall of my berth and am pushed even further down into the mattress. The ship rises slowly this time, stands still, and then dips down again. The bow dives into the next wave with a muffled thud. A glance at the clock: 3:24 a.m. – a good time to get up. We’ve almost reached the station, which means: action. Overnight, the seismographers found the best position for extracting sediment cores on the Mid-Atlantic Ridge. We will now use drilling machines to recover this climate evidence from a water depth of up to 4,000 meters.

We have reached the last days of our four-week expedition in the North Atlantic with the German research vessel Maria S. Merian. The journey began in cold and rainy Reykjavik, and the destination is almost 3,000 kilometers further south, near the mild Azores Islands. The purpose of this fall’s campaign is to study the deep-water circulation of recent geological history. The 20 scientists on board are raring to go. For many of them, it’s their first expedition. I’ve been in the North Atlantic many times, and fortunately don’t suffer from seasickness. Force 6 winds and 5-meter-high waves are typical conditions here. We’ve already been forced



Ralf Schiebel, 51, studies the ecology and geochemistry of modern and fossil organisms and their interactions with the CO₂ system. He studied geology in Kiel, did his postdoc research at the University of Tübingen, was a senior scientist at ETH Zurich, taught at the National Oceanography Centre in Southampton (UK), and was director of the Geological Institute at the University of Angers in France. He has been involved in the development of the Climate Geochemistry Department at the Max Planck Institute for Chemistry in Mainz since 2015.

to return home empty handed before, the equipment washed overboard and the ship severely damaged on an earlier campaign.

The chief engineer, one of the 24-strong crew, is proud of his ship: with its service water system and diesel-electric power, everything is well thought out and clean. Nowadays, waste is sorted on board, and the ship meets the requirements of the Blue Angel environmental label. In the early 1990s, waste was still disposed of at sea and the ship was run on marine diesel. Back then, you could talk to your loved ones on the telephone once a week at a cost of 20 Deutschmarks per minute. Today, there's e-mail and a telephone in the cabin.

A day after our departure, we reach the first station. The aim is to fish for plankton in the stormy sea. The 200-kilogram net goes over the ship's rail. It functions perfectly. The team works well together. Charlotte, a student from Kiel, stands at the side of the ship and Doro, a doctoral student from Mainz, is at the controls in the lab. Ten minutes later, the net rises from the waves again and crashes against the hull of the ship. The wind rushes in and there's water everywhere. The skipper isn't happy with us yet: "Hold on – better – always!" he shouts.

In the subtropical Atlantic, we focus on the sediment cores as indicators of climate development. We can't measure the temperature 8,000 years ago, but we can reconstruct it.

We celebrated hump-day of our expedition on board in fantastic weather on our way to the next station. We had lost all sense of time by then. Our daily rhythm is marked by meals. A warm meal, fruit, salad and fresh bread three times a day. One person's breakfast is another's dinner.

We've struck gold. The samples couldn't be better and spirits are high. The Atlantic is kind to us now. Nevertheless, I want to go home. My wife was on vacation with our baby visiting the grandparents. We wrote to each other and phoned every day. Will the little one be shy with me? We arrive in Ponta Delgada in the Azores at eight o'clock on a Friday morning. The ship is unloaded and reloaded; the next research expedition starts on Saturday. We'll be in a plane on our way to Frankfurt by then.

Snoozing between Heaven and Earth

For humans, even a brief bout of sleepiness while driving can have fatal consequences. Frigatebirds, on the other hand, can snooze while cruising through the air without crashing to the ground. What's more, they generally get by on very little sleep during their long flights over the open ocean, which can last for days. A team of scientists working with **Niels Rattenborg** at the **Max Planck Institute for Ornithology** in Seewiesen has demonstrated for the first time that birds can fly in sleep mode.

TEXT **ELKE MAIER**



The bar-tailed godwit, a member of the sandpiper family, is one of the avian world's record-holders. It may not be as big as an ostrich, as fast as a peregrine or as loud as the South American oilbird, but when it comes to non-stop flying, it surpasses them all. This bird can cover a distance of over 11,000 kilometers from its breeding ground in Alaska back to New Zealand. It com-

pletes this entire journey in just eight days without any stopovers – no breaks to allow its muscles to recover, or simply to rest.

Impressive though this may be, godwits are far from topping the list when it comes to long-distance flying: frigatebirds remain in the air for over two months without interruption, and

common swifts are able to fly for 300 days straight without landing. But how can these animals do this without any sleep at all?

Niels Rattenborg is Leader of the Avian Sleep Research Group at the Max Planck Institute for Ornithology in Seewiesen, south of Munich. An American with Danish roots, he has been work-

Nap in the nest: Two female frigatebirds recover from their latest hunting expeditions. In the background are the tents of the Seewiesen-based researchers.





Arriving on the island: For their research trip far from civilization, Niels Rattenborg and his colleagues must transport all essential supplies by boat. The sea lions aren't the least bit put off by the researchers' comings and goings (above). The female frigatebirds, such as this one being set free by biologist Bryson Voirin, also show little sign of shyness (below).



ing in this field for a good two decades. “Even as a child, I was fascinated by birds,” he explains. The fact that he ended up working on avian sleep owes to a vacation job: “During college, I worked in a sleep lab during the summer and over Christmas. I later worked there for ten years as a technician.”

As luck would have it, ornithology and sleep were easy to combine. Rattenborg studied biology, did his doctorate on the sleep behavior of mallard ducks and took up a position as a scientist in Wisconsin. He has been carrying out research in Seewiesen since 2005. He and his colleague Bryson Voirin have now provided proof that birds can actually sleep while flying.

FROM WORMS TO ELEPHANTS – EVERYONE HAS TO SLEEP

The question as to why organisms must sleep is one that has preoccupied scientists for generations. Whether we are talking about roundworms, fruit flies, fish, or elephants – no animal can get by for very long without sleep. Why this is the case is still not known. One attempt at providing an explanation is known in expert circles as the “synaptic homeostasis hypothesis.” According to this theory, the purpose of sleep is to clear the head: while we are awake, we are bombarded with huge amounts of information that need to be processed. To do this, new synapses are formed in the brain and existing connections expanded. “At some point, our heads would be so full that we wouldn’t be able to absorb anything new,” says Niels Rattenborg. To prevent this from happening, some connections are deleted while we sleep, generating new capacity.

The fact that the regions of the brain that have been very active during the day sleep particularly deeply at night supports this hypothesis. Niels Rattenborg and his colleagues observed this in pigeons: they showed them David Attenborough’s film *The Life of Birds* and kept them awake while the film was playing. Each bird had one eye covered during the film presentation. That night, the brain region responsible for the seeing eye slept more deeply than that associated with the covered eye.

But why do sleep requirements differ so widely across the animal kingdom? How is it that hedgehogs and bats sleep for up to 20 hours per day while giraffes can get by on just two hours? And what happens with birds that have no opportunity to make intermediate stops when flying over the open ocean? Do they sleep in the air? Do they refrain from sleeping temporarily? Or is it possible that their brains sleep in installments?

Rattenborg had already observed a fascinating phenomenon while doing his doctoral work on mallard ducks: in a group of sleeping ducks, those sitting at the edge kept their outwardly directed eye open and the corresponding brain hemisphere remained awake. In this way, the birds can rest a part of their brain while keeping an eye out for potential predators. Unihemispheric sleep, when only one half of the brain sleeps while the other remains awake, is found not only in birds, but also in dolphins, seals and manatees, for instance.

Other bird species, in contrast – such as the North American white-crowned sparrow – need far less sleep at certain times than they normally do.

While their conspecifics in the wild travel to their wintering grounds, white-crowned sparrows in captivity jump restlessly around their cages and beat their wings. As Rattenborg and his colleagues discovered, during this period, known as migratory unrest, the birds sleep only one-third of the amount they would normally sleep. Surprisingly, the sleep deprivation appears to have no negative impact on the birds: they perform learning and memory tasks just as well.

YOU SNOOZE, YOU LOSE

The Arctic pectoral sandpiper also manages perfectly well with little sleep. Together with a team of researchers from Seewiesen, Rattenborg observed that the males don’t allow themselves to rest very much during the three-week mating season. Instead, they invest all their energy in engaging in skirmishes with other males and in wooing the females. Paternity analyses have shown that this strategy serves them well: the males that slept the least had the most offspring. “So sexual selection encourages short sleeping in pectoral sandpipers,” says Rattenborg.

To find out how flying birds manage their sleep requirement, Niels Rattenborg and his colleagues joined forces with neurophysiologist Alexei Vyssotski from Zurich. Vyssotski developed miniature data-logging devices that are so light that they can be carried by birds even when flying. The devices record the birds’ head movements and wing beats and simultaneously measure their brain activity. To do this, the researchers attach sensors to the animals’ heads to measure variations in the volt-

Idyllic island: While working in the field, the scientists exchange their fixed abode for a spacious tent (left). Niels Rattenborg heads off from the camp to check on the frigatebirds (right).



age generated by the brain. The sensors record the electrical activity of millions of neurons in the waking state and during the different sleep phases, and depict characteristic wave patterns on an electroencephalogram (EEG). This development enabled the scientists to study the waking and sleep behavior of flying birds for the first time.

As their research subject, they chose the great frigatebird (*Fregata minor*). This is one of the biggest seabirds, with a weight of up to 1.5 kilograms and a wingspan of over 2 meters. The measuring device, including batteries, weighs just 12 grams and presents no great burden for the animals when flying.

Frigatebirds spend most of their time in the air and are perfectly adapted to this lifestyle. They mostly sail above the oceans without beating their wings, watching for flying fish and squid that are driven to the surface of the water by dolphins and predatory fish.

In the water, however, these consummate flyers are relatively helpless. "Their plumage isn't water-repellent and becomes completely saturated. They also have very small feet, which aren't good for swimming," says Rattenborg. So frigatebirds depend on being able to catch their prey from the air.

During their lengthy hunting expeditions, they aren't able to rest on the water like albatrosses, for example.

For their research on the frigatebirds, Rattenborg and Voirin collaborated with Sebastian Cruz, a seabird expert from Ecuador. Together they set up camp right next to a frigatebird colony on Genovesa, one of the small uninhabited islands in the Galapagos archipelago. "We had a kitchen tent and a laboratory tent to work in, and we slept under the open sky on hammocks," reports Voirin.

FEMALES MAKE BETTER TEST SUBJECTS

In the interest of sleep research, the scientists themselves also went without sleep: they began by locating the nests during the day and then returned to them at night to catch the birds. In this way, they kept the disruption to a minimum. Fortunately, the animals build their nests on bushes at a maximum height of 2.5 meters, so the researchers were spared having to embark on nocturnal climbing adventures. As the birds in the Galapagos have no natural predators, they're not timid around people and are thus easy to catch.

For their study, the researchers chose females as their test subjects. "Because they are bigger than the males, it's easier for them to carry the logging devices," says Rattenborg. "What's more, unlike the more easily disturbed males, we had the certainty that the females will always return to their young." With frigatebirds, both partners usually share the task of rearing the offspring. While one parent is off looking for food, the other one guards the nest against other members of their species who would be only too happy to swallow small, unguarded young birds.

In order to fit the logging devices onto the female birds, the scientists temporarily anesthetized them and took them to the laboratory. It took around 30 minutes to secure the devices to the birds' heads and backs using a special glue and tape. In addition to the devices for measuring brain activity, head movements and wing beats, the researchers also fitted the birds with GPS loggers that recorded their locations and flight altitudes. Once they were fully equipped, the researchers returned the feathered test subjects to their nests.

It was then a question of waiting until the frigatebirds headed off to



hunt for food. “Once they had flown away, we checked the nests regularly so that we wouldn’t miss their arrival back home,” says Voirin. Fortunately, everything went according to plan: the birds had returned after no more than ten days. It later emerged that they had covered distances of up to 3,000 kilometers in the interim.

The scientists then had to catch the birds again to access the data. They were able to read the data loggers on site and obtained data from a total of 14 birds. Five of them had been on their travels for so long that the memory capacity of the recording devices ran out before they returned. With the other nine birds, the devices had continued to record when they were already back in their nests. The biologists were thus able to compare their sleep behavior in the air and on land.

Back in Seewiesen, Rattenborg studied the recorded EEG graphs. “When they’re awake, the amplitudes are small, but the frequencies are high,” explains the Max Planck researcher. This pattern is due to the fact that the neurons in the brain fire unsynchronized electrical signals. Other EEGs were produced during deep sleep and presented higher amplitudes and

lower oscillation frequencies. In this state, the neurons synchronize and are alternately active and inactive, creating slowly oscillating brain waves. Deep sleep is thus also referred to as slow-wave sleep.

POWER NAPS REPLENISH ENERGY STORES

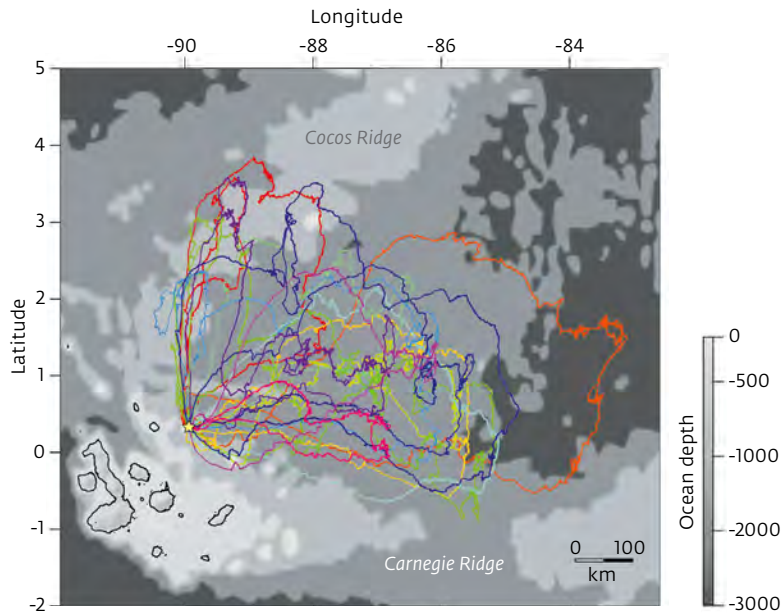
This kind of slow-wave sleep was evident on the EEGs recorded during flight. That was their proof: frigatebirds sleep while they fly and, to the scientists’ surprise, not only with half of the brain, but with both halves at the same time. “Even though they are able to fly when both halves of the brain are asleep, one side usually stays awake: the side associated with the eye that looks in the direction of flight. This is probably how the birds avoid collisions with other members of their species cruising through the same air stream.”

The animals usually doze in the early evening, shortly after sunset, when they are flying at a sufficient altitude and in a rising thermal – to protect them from falling. “This short sleep in the evening is probably a kind of power nap. It’s just enough to make up for the sleep deficit accumulated during

the day.” During the day, the birds are wide awake and concentrate fully on searching for food.

In addition to slow-wave sleep, the logging devices occasionally recorded short episodes of REM (rapid eye movement) sleep. EEG graphs with low amplitudes and high frequencies, which also occur in wakeful birds, are typical of REM sleep. REM sleep always occurs in both brain hemispheres, and is present not only in birds, but also in mammals, including humans. In mammals, REM phases last up to one hour, during which muscle tone is completely lost and the body goes limp. In birds, in contrast, REM sleep lasts only a few seconds and, although their muscle tone also falls, they can still stand or fly.

The function of REM sleep remains a mystery. Researchers assume, however, that it plays an important role in normal brain development. This is supported by the fact that most young mammals spend longer in REM sleep than their adult counterparts. In newborn human babies, it accounts for more than half of total sleep time, while it takes up only a quarter of sleep time in adults. Niels Rattenborg and his team observed a very similar pattern in



Frigatebirds make use of rising thermals as they glide over the ocean in search of food. This activity demands their full concentration. They usually allow themselves a short nap after sunset. However, they keep the eye looking in the direction of flight open, and the corresponding brain hemisphere awake (left). GPS loggers enable the researchers to precisely track the flight routes. The birds cover distances of several hundred kilometers per day (right).

birds. In a study they carried out on young barn owls, they established that the proportion of REM sleep declines with age in owlets, as well.

Thus, both slow-wave and REM sleep occur in flying frigatebirds. They apparently don't need to keep one part of the brain awake to keep themselves in the air. Nevertheless, the birds allow themselves hardly any time for sleeping while flying. Over a 24-hour period, they slept on average for a total of just 42 minutes, and the average stretch of sleep lasted just 12 seconds. The longest uninterrupted stretch of sleep recorded was just under six minutes. On land, in contrast, the animals slept over 12 hours. These sleep phases were not only longer (52 seconds), but also deeper. It would therefore appear that the animals make up for lost sleep, just as we humans do.

In an earlier study, the researchers in Seewiesen had already demonstrated that pigeons compensate for sleep deficits in a similar way: when the scientists deprived their test subjects of their usual midday nap, they slept more intensively that night. Unlike the frigatebirds, however, the pigeons quickly became tired when they were kept awake for just a few hours. "We constantly had to gently remind them to stay awake."

WANTED: A MIRACLE CURE FOR FATIGUE

But why don't the frigatebirds sleep for longer in the air if, as it seems, they can do this without difficulty? "An earlier study showed that they follow favorable sea currents to locate abundant food sources," says Rattenborg. "It's possible that they also stay awake at night so they can observe the surface of the water and ensure they are in the right place for eating first thing in the morning." This obviously requires the full attention of both brain hemispheres; otherwise, the birds would probably sleep more.

How the frigatebirds compensate for the negative impacts of sleep deprivation is still a mystery. Nor do the sci-

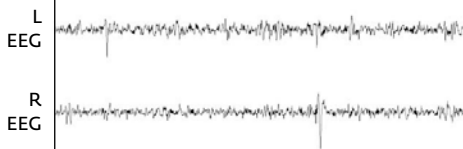
entists yet know why we humans find it almost impossible to suppress our sleep requirement. "Pigeons also get tired like people, but the frigatebirds simply carry on as usual!" The fact that humans and birds have developed very similar sleep patterns independently of each other gives the researchers hope that they will also learn something about human sleep from their avian sleep research findings.

Rattenborg even received a grant from the US military for his white-crowned sparrow project, but it didn't yield the miracle cure – enabling soldiers to withstand fatigue – for which they had likely secretly hoped. "Other occupational groups, such as rescue teams working in the aftermath of a natural disaster, would also benefit from such a substance," says Rattenborg. Wouldn't it also be helpful for him as a scientist to sleep less and be able to spend more time on his research? "Why not," he says, laughing.

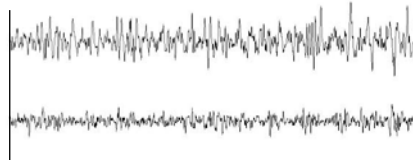
In any case, his research has already contributed indirectly to new insights into human sleep. Inspired by his research on the mallard ducks, scientists recently discovered that, like the ducks on the edge of the group who keep the outwardly directed eye open, humans keep parts of one brain hemisphere



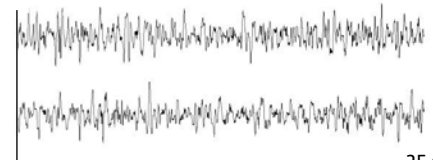
Waking state



Slow-wave sleep of one brain hemisphere



Slow-wave sleep of both brain hemispheres



25 s

Above Flying light: The tiny measuring device on the birds' heads records their brain activity (above).

Below The EEGs show the waking state (left) and slow-wave sleep patterns for one (center) and both brain hemispheres (right).

awake when they sleep in an unfamiliar environment. "So there's reason to think that we will also learn something about our own sleep from the sleep behavior of the frigatebirds."

Rattenborg would now like to fit bar-tailed godwits with mobile logging devices and accompany them on their journey from Alaska to New Zealand. "Unlike frigatebirds, they actively beat their wings when they fly," says the Max Planck researcher. The question is whether they sleep while doing this. To determine this, the researchers must first develop even smaller and lighter logging devices, as bar-tailed godwits are considerably smaller than frigatebirds. ◀

TO THE POINT

- Frigatebirds can sleep in flight. When this occurs, usually only one of their brain hemispheres sleeps, but occasionally, both sides do.
- When in flight, the birds sleep for a total of only around 42 minutes per day. Each period of sleep lasts just 12 seconds on average.
- Their brains can go into slow-wave and REM sleep during flight. While the musculature of mammals becomes completely limp during REM sleep, birds can still glide through the air.

GLOSSARY

REM sleep: Rapidly oscillating brain activity that is comparable to the waking state. Typical features of REM sleep are rapid eye movements and reduced muscle tone. The arousal threshold is very high and the majority of dreams occur during this phase in humans. Today, scientists think that REM sleep emerged at a very late stage in evolution and is present only in mammals and birds. However, there have recently been indications that some reptiles may also experience REM sleep.

Slow-wave sleep: Slow-wave sleep is the sleep phase with the highest arousal threshold, which explains its colloquial designation – deep sleep. Delta waves ("slow waves") with a frequency of less than four oscillations per second are characteristic of slow-wave sleep. These waves gradually spread through the entire brain. Thus, not all areas of the brain are in slow-wave sleep at the same time. The waves of activity probably play a role in the processing of information recorded by the brain while awake.

Metronomes that Regulate the Day

Ludwig II of Bavaria is a particularly striking example of how differently people's internal clocks can tick. According to historical sources, the monarch usually conducted his government business at night and slept during the day. Whether the Fairy Tale King had a disorder that disrupted his sleep-wake rhythm is a matter even **Gregor Eichele** can only speculate about. Nevertheless, Eichele and his team at the **Max Planck Institute for Biophysical Chemistry** in Göttingen have gained much new insight into how the body's natural timekeepers work.

TEXT **KLAUS WILHELM**

The sleep-wake cycle is intimately linked with our internal clock," says Gregor Eichele, who heads the Genes and Behaviour Department at the Max Planck Institute in Göttingen. Eichele knows first-hand how the internal clock can affect wellbeing: he commuted regularly between Germany and the US for many years. The circadian clock has long been one of his scientific passions.

Every day, millions of people experience how their sleep patterns are affected by their internal clock when they cross several time zones within the space of a few hours. This frequently results in their internal clocks getting out of sync. Some already complain of sleep disturbances when the clocks are turned back just one hour when daylight saving time ends. Even in the case of such small adjustments, it can take several days for the internal

and external clocks to re-synchronize before the affected individual is able to sleep as usual.

"Although sleep and the internal clock are related, they are fundamentally different. Whereas sleep is a function of the body as a whole, the internal clock is a property of individual cells," Gregor Eichele emphasizes. At the same time, the two influence each other. For example, neurons and sleep-regulating substances are controlled by the 24-hour circadian clock, which is thus responsible for ensuring that we fall asleep at the right time.

THE INTERNAL CLOCK RUNS A BIT SLOW

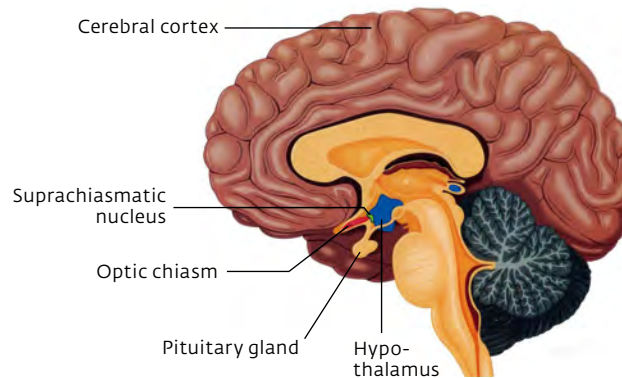
The word "circadian" is derived from the Latin *circa* (approximately) and *diem* (day). It expresses the fact that the internal clock only roughly follows a 24-hour rhythm. An individual can have a circa-

dian clock with a rhythm of, say, 24.7 hours. If that person lived for several weeks in a room that was always illuminated, he or she would fall asleep every day 42 minutes later than on the previous day. Environmental conditions – mainly light – act as timekeepers to continuously recalibrate the internal clock to a rhythm of exactly 24 hours.

This seemingly complex system exists because the daily cycle of day and night is not sufficient to synchronize the biological processes in our body. Consider, for example, the light-dark rhythm of modern life. If our physiological rhythms were merely a response to the presence or absence of light, any prolonged evening with all its artificial light sources would have catastrophic effects on our metabolism and sleep-wake rhythm. Instead, our internal clock recognizes these external time signals as spurious and keeps the body chronologically stable. >



The life rhythm of most animals follows an internal clock. In mice, for example, the timekeeper is naturally set in such a way that the animals are active at night and rest during the day.



Left Gregor Eichele is fascinated by clocks – especially the internal clocks that synchronize processes in our cells and organs. He has elucidated important elements of the molecular mechanism that regulates the circadian rhythm of cells.

Above The suprachiasmatic nucleus is the master clock in the human brain. Measuring just a few millimeters across, it is located above the site where the two optic nerves cross, and receives information they carry from the eyes about light conditions. The pituitary also produces hormones that affect the body's internal clocks.

The circadian clock probably arose at the dawn of evolution. The very first single-celled organisms in the primordial seas may have benefited from an ability to anticipate the sunrise and to descend into deeper waters to avoid it. In this way, they escaped from the UV radiation of the Sun, which at the time was still essentially unfiltered. In the darkness of the deep sea, the clock then signalled to the microbes when it was time to surface again.

Since they evolved, virtually all life forms have retained the internal circadian clock. It is beneficial for plants to carry out photosynthesis only during the day. In diurnal mammals such as humans, body temperature rises before waking. The release of the stress hormone cortisol peaks in the morning to boost physical and mental performance. Metabolism, muscle tone, renal function and concentration fluctuate over the course of a day.

There is a molecular clock for every cell, every tissue, every organ – whether the liver, kidneys, heart, gut, immune system or skin – and for the body as a whole. “We have an entire shop full

of clocks,” says Eichele. Being Swiss, you might say he is predestined to analyze such mechanisms. In order for all the clocks to display the same time, they must all be continuously synchronized with the 24-hour light-dark cycle of the environment – all the cell clocks and the organ clocks, as well as the body as a whole.

THE BRAIN NUCLEUS SETS THE RHYTHM

The most important clock, the suprachiasmatic nucleus, is located in the brain. Within this nucleus are 50,000 interlinked neurons that are also connected to neurons in other brain regions. The nucleus receives signals through nerve fibers from specialized sensory cells in the eyes. When light strikes a light-sensitive pigment in the sensory cells of the retina, they generate an electrical signal, which is relayed to the suprachiasmatic nucleus.

Without the suprachiasmatic nucleus, hamsters, for example, lose their daily rhythm. Scientists measured this by placing a treadmill in the cage and

recording the rotations of the wheel as a measure of the hamsters’ activity. Hamsters are normally active primarily between sunset and sunrise. Without a suprachiasmatic nucleus, however, they were just as likely to exercise during the day as during the night – yet the animals didn’t sleep more than usual.

This finding suggests that the nucleus, as the master clock, relays information to all the other clocks in the body’s cells, tissues and organs, and synchronizes them both with the day and with each other. Recent research, however, has called this theory into question: Eichele’s team modified mice genetically in such a way that the important clock gene *Bmal1* is inactive in the suprachiasmatic nucleus. Their experiments differ from the hamster studies in that the connections to and from the nucleus are left intact. Nevertheless, according to the theory, the animals’ internal clocks should go haywire.

But that doesn’t happen! “We found that the other circadian clocks remain synchronized even without the master clock in the suprachiasmatic nucleus,” Eichele explains – at least when light

and dark alternate in a 24-hour rhythm. However, if mice lacking the clock gene are kept in permanent darkness, chaos ensues and they have problems keeping their internal clocks in sync.

The body thus needs the natural light-dark cycle as a timekeeper. Although food intake can calibrate the circadian clock to a precise 24-hour rhythm, it results in only semi-synchronized internal clocks. Evidently the clock system is organized like a federal country that is able to keep the individual regional governments running even if the federal government sometimes

grows weak. "This system is ultimately more stable than one that relies exclusively on the suprachiasmatic nucleus," Eichele says.

But how do internal clocks synchronize without the master pacemaker in the brain? One possibility is that the body's clocks receive light-dark information from the suprachiasmatic nucleus. Researchers have shown that light can activate clock genes in organs such as the liver via the autonomous nervous system.

If the nucleus is absent, light signals travelling from the eyes into the body

also peter out. Light then no longer has an effect on the autonomous nervous system or the body's clocks. As the scientists in Göttingen only switch off a single clock gene and not the entire neural nucleus, light signals are still able to reach and synchronize the other clocks in the body via the nucleus. The signals evidently don't have to be pre-processed in the clock cells of the nucleus.

However, it is also possible that other important clocks in the brain stand in for the suprachiasmatic nucleus and synchronize the body's clocks. A likely candidate would be the pituitary gland,

DO CILIA IN OUR BRAIN REGULATE OUR SLEEP?

There is a cavity system located deep within the human brain: four cavities, called ventricles, are connected to each other via channels that act as conduits for cerebrospinal fluid. This fluid contains, among other things, neuropeptides, which ensure, for example, that we become tired. The suprachiasmatic nucleus (see text), believed to be the seat of the internal clock, is located near one of the ventricles. Scientists at the Max Planck Institute for Biophysical Chemistry and the Max Planck Institute for Dynamics and Self-Organization recently discovered that eyelash-like processes,

called cilia, on the wall cells of the ventricles can change their direction of motion and thus alter the direction in which the cerebrospinal fluid flows. At certain times of the day, they even produce eddies that act as barriers. It is still not definitively known whether the distribution of the fluid, and consequently the sleep-inducing neuropeptides, actually follow a circadian rhythm. The researchers may have discovered an entirely new mechanism that is based, not on the activity of neurons, but on the activity of wall cells in the ventricles.



which also receives light signals from the eyes. Located at the base of the brain, the gland releases the hormone ACTH into the bloodstream. It is then transported to the adrenal glands, where it triggers the release of cortisol, adrenalin and noradrenalin.

These stress hormones are known to be important pacemakers for the internal clocks. Eichele and his team discovered that mice with a defective clock gene rhythmically release the hormone corticosterone in the course of the day in sync with other body clocks – almost as in normal mice. This hormone is analogous to cortisol in humans. “It’s possible that corticosterone synchronizes the body’s clocks if the suprachi-

asmatic nucleus fails as a timekeeper,” Eichele concludes. This suggests that the internal clock in the adrenal glands is almost as important as the clock in the suprachiasmatic nucleus.

CHRONOTYPE DETERMINES WHEN YOU GO TO BED

But the clocks in the body’s tissues and organs are influenced not only by light, but also by sleep. “You have to be relaxed, free of stress and able to sleep when you want, meaning in accordance with your personal chronotype, which determines whether you go to bed early or late and tend to sleep for short or long periods,” says Henrik Oster of the

University of Lübeck, who led a research group at the Max Planck Institute in Göttingen until the end of 2012.

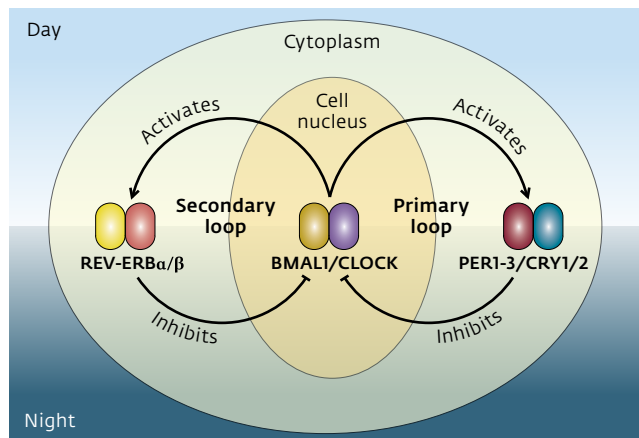
Since Oster’s time in Göttingen, he and his colleagues have been studying the relationships between sleep, the internal clock and metabolism. They observed, for example, that the liver and fat cells of mice with sleep disorders no longer operate in sync. The researchers want to determine whether the rhythm of the cells of other organs, such as the kidneys, is also decoupled.

A lot of evidence suggests that sleep disorders can also alter metabolism via the internal clock. For example, Oster and his colleagues at the Max Planck Institute knocked the sleep rhythm and

Left Henrik Oster keeps his mice under precisely controlled light-dark conditions. The cages are in cabinets in which the light duration and intensity can be programmed, allowing the animals’ sleep-wake rhythm to be controlled.

Right top, bottom Mice are very curious animals – so much so that their curiosity even stops them from sleeping. The cages thus contain unfamiliar objects for the mice to explore to their heart’s content – a particularly stress-free form of sleep deprivation.





Two feedback loops control a cell's circadian rhythm through an interplay of gene activation and gene inhibition. Every morning, the BMAL1 and CLOCK proteins in the cell nucleus stimulate the production of cryptochrome (CRY) and period (PER) proteins. These proteins accumulate in the cell plasma and migrate over the course of the afternoon and evening back into the cellular nucleus, where they block the BMAL1 and CLOCK proteins. During the night, levels of CRY and PER in the cell decrease to the extent that the blockade of CLOCK and BMAL1 ceases. In the morning, a new round of CRY and PER production starts again. This cycle is stabilized by another feedback loop in which BMAL1 and CLOCK stimulate the production of REV-ERB proteins, which progressively switch off the Bmal1 and clock genes over the course of the day. As a result, the production of the REV-ERB proteins decreases so that BMAL1 and CLOCK can be produced again in the early morning.

thus the internal clock out of sync in mice. They prevented the animals from sleeping in the morning by placing toys in their cages. After a few days, they found that the disrupted sleep pattern had an impact on the internal clocks of peripheral organs, which were then no longer able to switch important metabolic genes on and off.

One example of such a metabolic disturbance is hormone-sensitive lipase. Normally, the circadian rhythm ensures that this lipid-cell enzyme is active during the sleep phase, when it breaks down stored fats that the body needs to bridge the period without food. However, because lipase activity is lower in the case of sleep disorders, little fat is released into the body. "This causes blood glucose levels to fall, an energy emergency results, and the animals get hungry," Oster says. The mice start to eat, which then really disrupts their sleep patterns. The result is a vicious circle that causes the animals to gain more and more weight. To complicate matters, hormones in the stomach reset the liver's clock if the mice eat when they should actually be asleep. Consequently, the liver's metabolism becomes increasingly imbalanced.

Is the body somehow able to compensate for this metabolic chaos? The answer is yes, in some circumstances. Oster's team disturbed sleeping mice and provided access to food only during their normal waking phase, but allowed them to eat as much as they wanted. "That normalized activation of the clock genes in the liver," Oster

says. "So it appears that the time of food intake is a very important factor in the development of obesity and metabolic diseases."

The researchers in Lübeck also observed that clock genes cause metabolic changes in sleep-deprived humans, as well. Whether that really can lead to obesity and diabetes hasn't been established. However, studies of shift workers suggest that that is, in fact, the case.

In any case, the mice experiments clearly show that the correct synchroni-

zation of sleep and food intake can compensate for many metabolic imbalances – and perhaps even reverse some of them. For this and other reasons, Oster believes that stabilizing the internal rhythm can be an important factor in the treatment of metabolic diseases. After all, these disorders follow a pronounced daily rhythm and are influenced by stress. Sleep plays a key role here. "If you get sufficient sleep, and get it at the right time," Oster says, "you'll be less susceptible to these disorders." ◀

TO THE POINT

- **Sleep and the internal clock are closely associated: if the internal clock gets out of sync, sleep problems can develop. And individuals who sleep poorly or irregularly disrupt their internal clock.**
- **Cells and organs follow their own internal clock. The suprachiasmatic nucleus, a cluster of neurons in the brain, is the master timekeeper for other clocks in the body. However, they can also function without the nucleus. Some of them receive light/dark information directly from the eyes.**
- **Sleep disorders can trigger metabolic disorders by throwing the activity of clock genes into confusion, disrupting metabolic processes.**

GLOSSARY

Nucleus: A cluster of neurons within the central nervous system. The cells of a nucleus usually have the same or at least similar tasks. Nuclei represent another pattern of how neurons can be arranged in the brain besides in layers. In vertebrates, there are hundreds of such nuclei located in deep-lying regions of the brain, where they are surrounded by a type of tissue known as white matter, through which nerve fibers run.

Circadian rhythm: Some biological processes follow an approximately 24-hour rhythm. This rhythm is regulated by genes whose activity controls metabolic processes in cells, organs and the body as a whole, and thus also behavior. The rhythm is self-regulating, meaning that it requires no external timekeeper. However, outside factors can recalibrate the rhythm of the body's clocks. In diurnal organisms, the circadian rhythm is usually somewhat longer than 24 hours, while it is somewhat shorter in nocturnal animals (Aschoff rule).

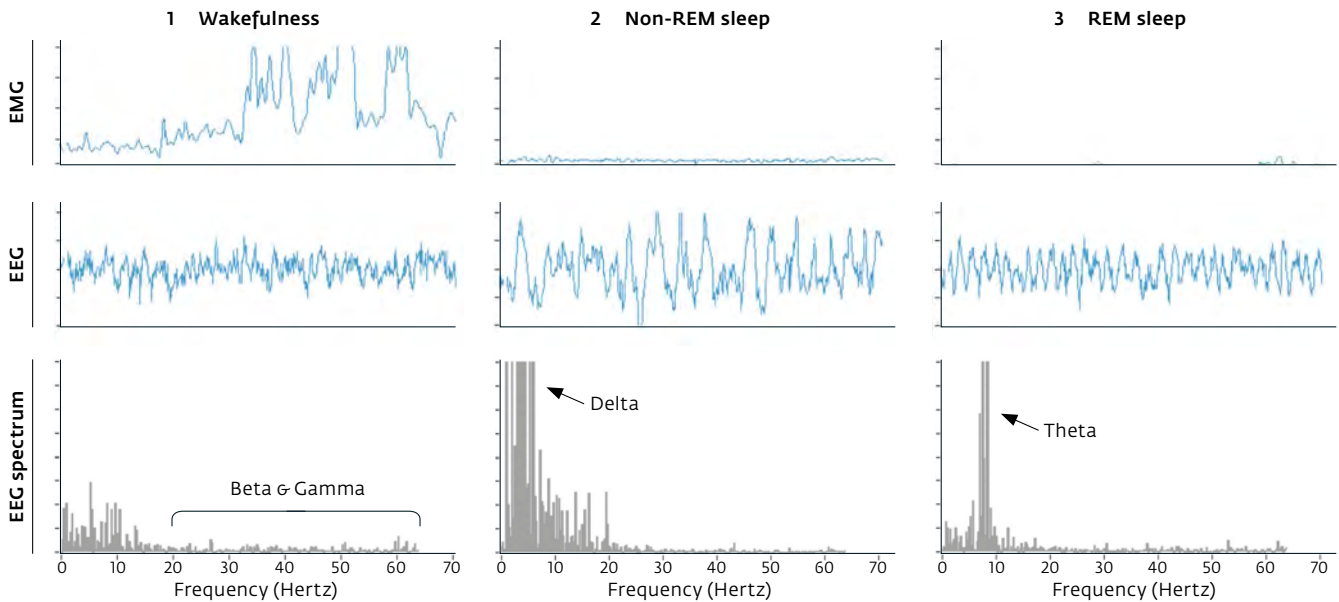
High-tech nightcap: Researchers use more than 100 electrodes to record the electrical currents on the surface of the head while a subject sleeps. This brain activity is used to generate a sleep profile.



When the Brain Switches to Standby

People who haven't gotten enough sleep often see the world as a fairly sad place. If their tiredness lasts for weeks or even months, their dark mood may become chronic and develop into depression. Conversely, depression is frequently also associated with severe sleep disorders. **Axel Steiger** and his team at the **Max Planck Institute of Psychiatry** in Munich are studying the connection between disturbed sleep and depression. To do this, they measure human brain activity in the sleep lab.

TEXT **CATARINA PIETSCHMANN**



Top Measuring mouse sleep: While awake (column 1), mice move around a lot, so their muscles are more frequently active. The graph shows the electrical signals from their neck muscles (electromyograph; top). The neurons in their brain fire in different rhythms and across a broad range of frequencies (middle and bottom). In non-REM sleep (column 2), the skeletal muscles become inactive (top). Brain activity oscillates with high amplitudes but low frequency (delta waves; middle and bottom). In REM sleep (column 3), the muscle tones are almost flat (top) and theta rhythms predominate in the brain (middle and bottom).

Opposite page In the sleep lab of the Max Planck Institute of Psychiatry, Michael Czisch records the subject's brain activity in an MRI scanner. This device makes the activity of the sleeping brain visible to scientists.

Stress at work, relationship issues or moving to another city can literally rob people of their sleep. According to the Robert Koch Institute, one out of every three German citizens has suffered from a sleep disorder at some stage in their life. In most cases, sleep patterns return to normal once the stressful event or issue has passed. However, when such symptoms persist for weeks or months, it is important to consult a doctor.

Poor sleep can have physical or mental causes. “Disturbed sleep can be both a cause and a consequence of depression – in other words, it is both a symptom and a risk factor. It leads to a huge increase in the risk of depression,” explains Axel Steiger, Senior Physician and Head of the Outpatient Clinic for

Sleep Medicine at the Max Planck Institute of Psychiatry in Munich.

The long-standing clinic, which focuses on stress-related complaints such as depression, sleep disorders and anxiety, was founded by Emil Kraepelin in 1917 as the German Research Institute for Psychiatry, and became a member of the Kaiser Wilhelm Society in 1924. It contains five wards with a total of 120 beds, a day clinic, a number of special outpatient clinics and several research institutions, all under one roof.

SNOOZING IN THE NAME OF SCIENCE

Patients can voluntarily choose to take part in scientific studies – for Steiger, who has led the Sleep Endocrinology Research Group since 1991, it is an ide-

al environment for his research. He and his team study the connection between sleep patterns and nocturnal hormone release in depression. While the volunteers spend a night in the sleep lab, the scientists measure the electrical impulses of their brain and muscles, record their eye movements and regularly take small blood samples to assess the levels of certain hormones.

The researchers then use the wave patterns from the electroencephalogram (EEG) along with the other measurements to extrapolate the sequence of the different sleep stages, also known as the sleep profile, or hypnogram. This is a step-like diagram consisting of several phases: At the start of the night, the subject gradually falls into a deeper sleep, and the amplitude of the EEG waves increases as this oc-



curs. The EEG amplitude is low when the subject is awake or in REM sleep, and high during deep sleep, the lowest rung on the ladder.

The Institute also uses high-density EEG (HD-EEG), the newest technology in this area, to evaluate brain activity. Subjects wear a kind of “nightcap” fitted to the head with 118 fine electrodes – normally there are ten. While they slumber in the soundproof room, their brain, facial muscles and heart send a

continual stream of data down the wires to a computer. This allows the researchers to look into the cerebral cortex and even deeper parts, such as the limbic system, the seat of the emotions.

Schematic representations of the hypnogram show clear differences between REM (rapid eye movement) sleep, when dreaming typically occurs, and non-REM sleep. REM sleep appears as a stage below the waking state but clearly above that of deep sleep. It is

characterized by increased blood pressure and pulse, while the skeletal muscles remain fully relaxed. Four, five or sometimes even six or more cycles of deep sleep and REM sleep per night are typical. Deep sleep is a component of non-REM sleep. In healthy young people, it is most pronounced at the start of the night and occurs only rarely or not at all in the early morning.

Directly after falling asleep, most people sleep especially deeply for about

LEARNING WHILE ASLEEP

While asleep, the body is at rest only on the outside, because sleep is an active process: metabolism is running at full speed, particularly in terms of growth and regeneration, detoxification and tissue repair. Some parts of the brain are also highly active, processing the stimuli that the brain absorbed during the day, separating important information from irrelevant details, and moving memories from short-term to long-term storage. That’s why good sleep promotes good memory.

The need for sleep decreases continuously during the course of a lifetime. In the first three months of life, infants

sleep for up to 17 hours a day. This is due to the enormous growth and maturing processes that occur in the brain during this time. Never again do humans learn so much as in the first weeks and months of life. Three- to five-year-olds can manage on 10 to 13 hours, while seven to eight hours is generally enough for 18- to 78-year-olds. The sleep-wake cycle also changes. Adults generally sleep only at night and for a single stretch, while newborns take a number of shorter sleeps over the course of a day. By the age of one, most children already sleep through the night, and their daytime sleep decreases noticeably.



Axel Steiger has devoted nearly his entire research life to sleep. Among other things, he is Head of the Outpatient Clinic for Sleep Medicine at the Max Planck Institute of Psychiatry. There, various disorders are diagnosed and treated, such as nighttime sleep and movement disorders, unusual sleep behaviors (such as sleepwalking), and night terrors and nightmares.

90 minutes. This is followed by the first REM period. “Depressed patients, on the other hand, progress to REM sleep faster, sometimes after just ten minutes,” says Steiger. In addition, the first REM period is generally longer in these patients.

If we compare patterns of hormone secretion with sleep profiles, it is notable that less growth hormone is released in depressed patients than in healthy subjects. The cortisol values are also different, climbing much higher in many patients, especially in the second half of the night.

Cortisol is an important stress hormone. Its production is regulated by the brain by means of corticotropin-re-

leasing hormone (CRH). In the event of an infection, for example, CRH indirectly stimulates the release of cortisol in the adrenal glands. The cortisol then activates the immune system. The same thing happens in the event of exam stress or a heated argument. Once the situation has passed, the stress hormones come back into balance. At this stage, the cortisol already circulating slows CRH release and hence its own production.

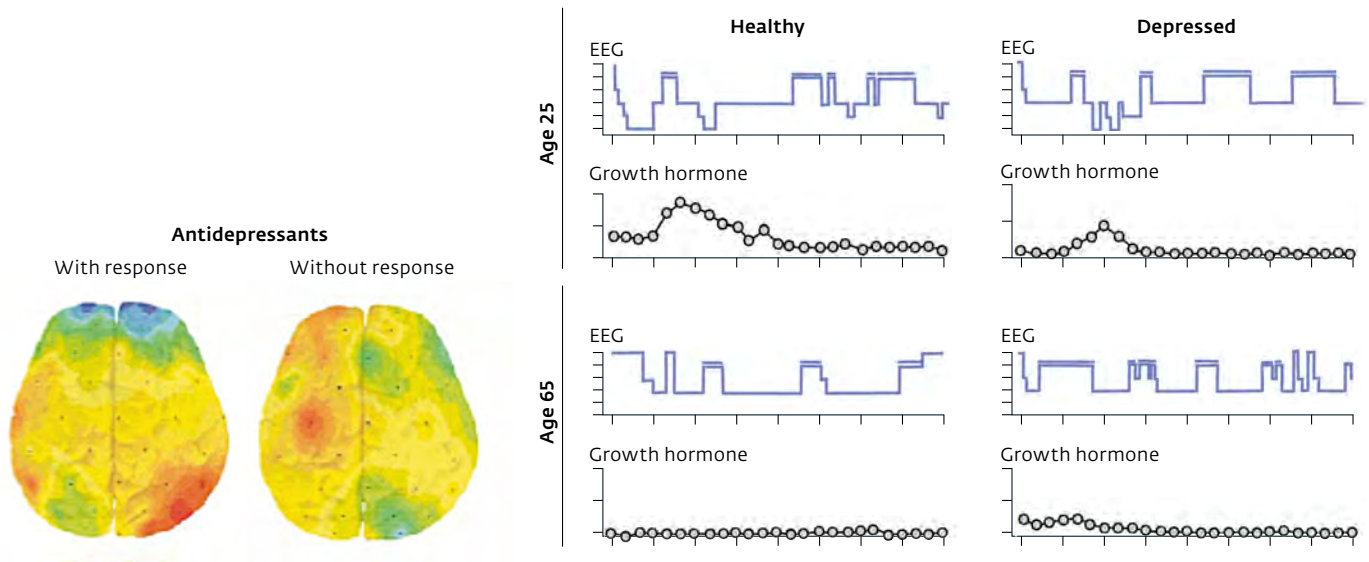
HORMONE INTERACTION AS A FOCUS OF RESEARCH

“We believe that this feedback mechanism is dysfunctional in patients with depression, probably because the cortisol receptors in the brain that stop the release of the hormone in healthy individuals are faulty,” explains Steiger. When depression subsides, the cortisol levels initially fall, while the sleep pattern remains disturbed for a time.

This interaction between CRH and cortisol also occurs in mice. Mayumi

Kimura, head of the Sleep and Telemetry Core Unit in the Institute, used rodent models in which specific genes were intentionally switched off or activated in order to study their exact function. Animals that have been stressed for extended periods, as well as those that have been genetically modified so that their brains produce more CRH than usual, fell faster and more frequently into a REM episode when asleep. This makes them the ideal animal models for depression.

But are there really depressed mice? “Of course we don’t know whether they really feel like human patients, but their sleep phenotype is certainly similar to that of depressed patients,” says Kimura. In the “forced swim” test, for example, whereas healthy mice swim around and try to struggle through longer, “depressed” mice give up sooner. And although mice generally wake more frequently and seldom sleep for longer than ten minutes at a time, the REM sleep profile of mice with elevated CRH production bears a



Left Differences in “cordance”: Following treatment with the antidepressants fluoxetine or venlafaxine, depressed patients show different patterns of brain activity. After one week of treatment, the theta-wave activity in the prefrontal cortex is lower in patients who respond to treatment (left, blue) than in patients for whom these drugs have no effect (right).

Right Sleep profile and hormone production change with age: While 25-year-olds slip quickly into deep sleep (top left, EEG), 65-year-olds take longer. When young people fall asleep, growth hormones are produced (left, top light-blue curve), but this doesn’t occur with older people (bottom left). Young people with depression (top right) take as long as elderly people to fall into deep sleep (EEG), and their brains release less growth hormone (right, top light-blue curve).

striking resemblance to that of depressed patients.

Returning to humans: it is striking that the sleep pattern of depressed patients resembles that of healthy elderly people. “Some depressions are actually like premature aging,” affirms Steiger. In old age, there is less deep sleep each night, and subjects wake more often and sleep less overall.

The fact that more women are affected by depression than men is apparently no coincidence. Hormonal fluctuations during their cycle, pregnancy and as a result of menopause contribute to women of fertile age being two to three times more likely to suffer from depression than men. The risk also remains higher during menopause. Conversely, female sex hormones provide protection against psychosis, which may explain why men develop schizophrenia earlier in life than women.

In addition to stress, age and gender, certain genes can increase the risk of depression in healthy individuals. In an earlier study, researchers at the Max

Planck Institute observed that the children and siblings of depressed patients had a higher rate of rapid eye movements in the first REM period, even though they themselves were healthy. “We also discovered that healthy subjects can have conspicuous sleep patterns if they possess certain risk genes for depression,” explains Axel Steiger. Previous investigations at the Institute found that one of these genes, P2RX7, is associated with unipolar depression.

MICE WITH A HUMAN DEPRESSION GENE

The influence of depression risk genes on sleep has also been observed in mice. Having provided the animals with the human version of the P2RX7 variant, Mayumi Kimura and her colleagues recorded their sleep patterns and discovered marked changes in their EEG patterns, similar to those of depressed patients. Kimura now hopes to use the genetically modified mice to study the effect of new antidepressants.

Genes also influence how well an antidepressant works in a patient. The gene ABCB1 exists in two variants that determine how efficiently certain drugs cross the blood-brain barrier. A DNA test has now been developed, enabling doctors to test which class of drugs is most suitable for their patient before starting treatment.

So there are different genes that increase the risk of depression. This leads the researchers to believe that there are also different forms of depression, depending on the gene. To date, the psychiatric classification of depression is based on the symptoms. However, different diseases can trigger the same symptoms. “Sleep profiles could help to distinguish between different types of depression. But we don’t yet know the exact connection between sleep patterns and genes,” says Steiger.

But sleep can not only aid in diagnosis, it can also play a role in treatment. Short-term sleep deprivation, especially in the second half of the night, has turned out to be a blessing



Tommi Bauer assesses the blood samples of subjects and patients. The levels of different hormones in the blood provide him with clues about the processes that occur in the human body while we sleep.

in psychiatry, as it has a very fast-working antidepressant effect. “We use it with patient groups twice a week at the clinic. The participants get up at two thirty in the morning and go for a walk with students. They chat together or pass the time until morning playing board games,” explains Steiger. The following evening, they go to bed as usual.

During a sleepless night, the body produces more mood-lifting substances, such as serotonin and tryptophan, than it would while sleeping. Sleep disturbance is thus a double-edged sword: on the one hand, it is a risk factor for depression, but on the other hand, sleep deprivation has an antidepressant effect. “However, this is a ray of hope for patients, because it allows us to show them that their situation is not nearly as hopeless as they think,” says Steiger. “They sense that their brain is not irrevocably flawed.”

Sleep profiles thus provide clues to depression and other mental disorders. Steiger hopes that they will also enable doctors to detect early on whether patients will respond to antidepressants. “In the past, it has always taken four to five weeks before we knew whether a patient was responding to a drug or

not. Now, after just one week of treatment, we can use REM sleep data to extract a parameter for local brain activity (cordance) and see whether it’s working,” says Steiger.

For the last 30 years, there have been no new breakthroughs in treating

depression with medication. However, a precise classification of the different forms of depression may one day enable doctors to more rapidly identify the most suitable drugs for their patients. One of the keys to making this a reality lies in sleep. ◀

TO THE POINT

- Disturbed sleep can be both a cause and a consequence of depression. Conspicuous sleep profiles can thus indicate depression.
- Scientists want to draw on sleep profiles to classify different forms of depression.
- Hormone production during sleep is different in healthy and depressed subjects. In depression, cortisol values are more elevated during the second half of the night – presumably due to a defect in the receptor molecules that suppress cortisol production in healthy individuals.

GLOSSARY

ABCB1 gene: This gene is active in cells on the inside of small blood vessels in the brain. It actively transports certain substances back to the blood, thus preventing them from reaching the brain. This includes a number of antidepressants. The two variants of the ABCB1 gene carry out this task with different degrees of effectiveness. A test can determine which variant a given patient possesses and predict how that patient would respond to an antidepressant.

P2RX7 gene: This gene contains the information for a calcium channel in the membranes of neurons and glial cells in different regions of the brain. It influences signal transmission between cells and in the brain. There are indications that both unipolar and bipolar depression are caused in part by changes in this gene.

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Earth-like Planet near Proxima Centauri

Astronomers discover a celestial body in the habitable zone around our nearest fixed star

Located just over four light-years away, Proxima Centauri is the nearest star outside our solar system. Astronomers, including a team at the Max Planck Institute for Astronomy,

have discovered a planet that orbits Proxima Centauri once every 11.2 days at a distance of 7 million kilometers – within a region that may just offer the right conditions for the emergence of life. The mass of the celestial body, called Proxima Centauri b, is estimated to be around 1.3 times that of Earth. The star has long commanded the attention of scientists because of continuous violent eruptions on its surface and resulting fluctuations in its brightness. The astronomers examined Proxima Centauri on 54 nights using HARPS, an instrument attached to the ESO 3.6-meter telescope in La Silla. The planet gave itself away because it exerts a gravitational force on the star it orbits, producing characteristic line shifts in the star's spectrum. (www.mpg.de/10696319)



Brave new world: An artist's impression shows the Earth-like planet orbiting the star Proxima Centauri, which is 4.24 light-years away.

Mass Panic in a Computer

Study simulates human behavior during building evacuations

When people flee a building to escape a terrorist attack or a fire, the result is often mass panic. Until now, it was nearly impossible to examine exactly what happens. In collaboration with an international team, scientists at the Max Planck Institute for Human Development have now developed a virtual scenario for this purpose. In the study, 36 participants navigated avatars through virtual rooms. The researchers were able to show that participants' behavior in the virtual environment was largely consistent with real-world behaviors. As in a real emergency, 95 percent of the participants moved to the right to avoid colliding with each other. The researchers investigated behavior in an emergency situation by simulating

the evacuation of a complex building. They induced stress in the participants by exerting time and financial pressure, as well as creating an environment with poor lighting, red flashing lights and fires at blocked exits. Their analysis

showed that crowding, jostling and herd behavior escalated rapidly in response to stress. The researchers hope that their simulations will prove useful for future testing and optimization of evacuation plans. (www.mpg.de/10732302)



Drama in Duisburg: On July 24, 2010, thousands of Love Parade visitors thronged in front of the tunnel where a mass panic broke out.

How Words Sound Is No Coincidence

Certain sounds are preferred or avoided even in unrelated languages

One of the tenets of linguistics apparently no longer holds. Up to now, linguists assumed that the association between how words sound and what they mean is largely arbitrary. Cases such as the use of the letter “m” in the word for “mother” in many languages were previously considered rare exceptions to this rule. An international research team involving researchers from the Max Planck Institutes for Mathematics in the Sciences and the Science of Human History, as well as from Leipzig University, carried out a comprehensive analysis that lays this assumption to rest. For the study, the researchers used data from more than two-thirds of the

6,000-plus languages spoken throughout the world – and found that many meanings are associated particularly often or particularly rarely with specific sounds, even in unrelated languages. This is particularly true of the names of body parts. For example, the letters o, u, p, k and q frequently occur in words for “knee”. The researchers are at a loss to explain why such coherencies exist. Linguists have now lost a tool that used to serve to establish relatedness, namely the occurrence of similar sound-meaning relationships. (www.mpg.de/10731041)

People all across the world prefer certain sounds for many concepts and avoid others.



The Call of the Dung

Vinegar fly excrement contains sex pheromones and invites other conspecifics to join the feast

Drosophila melanogaster has a good nose. For example, the fragrance of ripe fruit guides the vinegar fly to food and potential mates. The female not only eats the fruit, but also mates and lays her eggs there. Another important source of scents for the flies had been overlooked until now: their excrement. A team at the Max Planck Institute for Chemical Ecology in Jena discovered that the excrement of vinegar flies also contains pheromones that affect the behavior of other flies of the same species. The pheromones of males and females differ, allowing the insects to determine from afar whether there are potential partners at the site. The insects also benefit if many flies of the same species join the feast. The fly larvae that hatch out of the fruit appear to be able to assimilate the food more easily if it has been predigested by microorganisms contained in the excrement of fellow flies. Excrement is thus an important communication tool for vinegar

flies – and possibly also other species, such as the spotted-wing drosophila, *Drosophila suzukii*. If this difficult-to-control pest in orchards and vineyards is also attracted by its own feces, its excrement could conceivably be used to lure it into traps. (www.mpg.de/10733681)



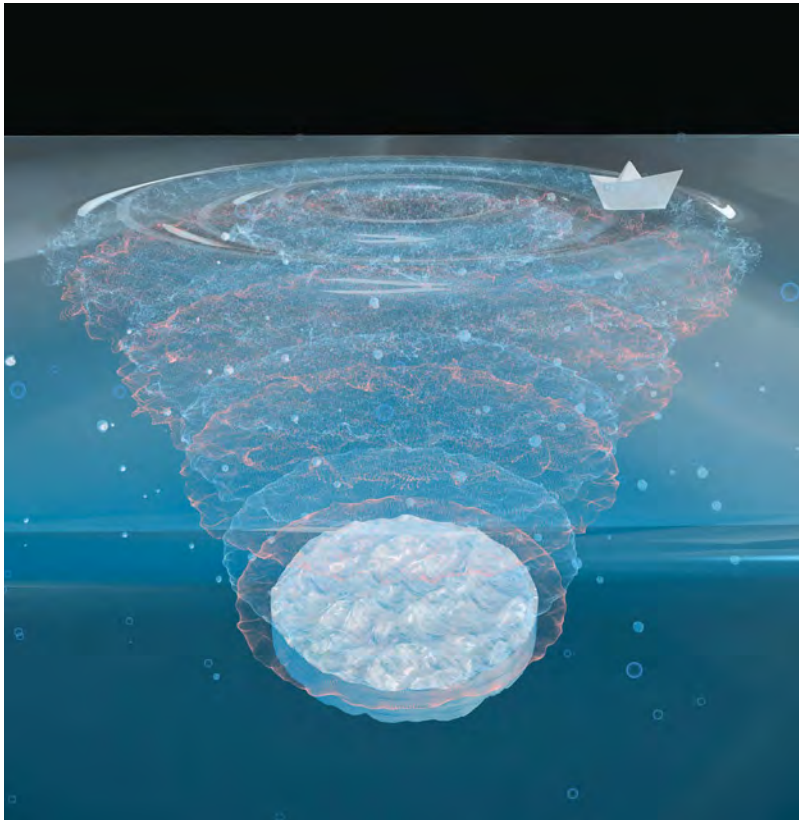
Many vinegar flies have already feasted on this blueberry. The magnification shows small spots where the flies have left their excrement. The smell of feces makes the fruit even more attractive to the insects.

Resistance Comes at a Price

Almost half our genes can be the starting point for diseases. Some 11,000 genes occur in the human genome in variants that can cause disease. Scientists from the Max Planck Institute for Evolutionary Biology in Plön have studied why such high-risk genes persist in the human genome instead of being eliminated by selection. Their analyses suggest that continuous adaptation to new pathogens in the course of evolution has increased the diversity of our immune genes, but that this comes at a price. According to the researchers, such diversity also extends to neighboring DNA segments, where it results in the persistence of harmful gene variants. Genetic diseases can thus be traced back to contact with pathogens that humans encountered in the course of evolution. (www.mpg.de/10713899)

Holograms with Sound

A new way of shaping waves in 3D could find applications in technology and medicine



It will soon be possible to easily make sound three-dimensional. Researchers from the Max Planck Institute for Intelligent Systems and the University of Stuttgart have found an easy way to produce an acoustic hologram. It works in much the same way as its optical counterpart, which uses the phase shift of light waves to produce a three-dimensional image. The acoustic hologram created by the Max Planck researchers is a plastic relief through which sound waves travel faster than through the surrounding area. Because of the varying thickness of the material, the profile of the acoustic pressure changes as it passes through the plastic relief. With the help of this finely modulated acoustic pressure, particles ranging in size from several micrometers to several millimeters can be shifted to form larger structures. The technique could also be used to improve ultrasound diagnostics in medicine and materials testing. (www.mpg.de/10741300)

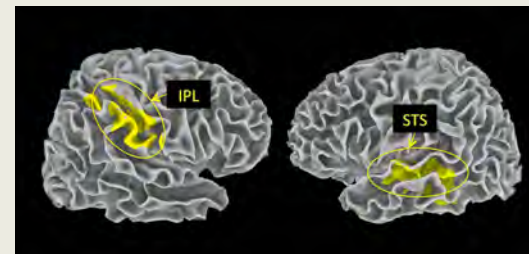
Ultrasound-driven surfer: On the surface of water, a hologram can be used to produce a standing wave on which a paper boat rides in circles.

Good and Evil in the Brain

Two areas are involved in networks that interpret situations positively or negatively

When someone offends you while smiling, should your brain interpret it as a genuine smile or as an offense? Such ambiguous situations are difficult for our brain to interpret. The same sentence can take on different meanings depending on the tone of voice. Researchers at the Max Planck Institute for Human Cognitive and Brain Sciences in Leipzig have identified how the brain interprets such scenarios. They found that two networks in the brain determine how we interpret situations. The one is active when we perceive a scene as positive, and

the other when we have negative impressions. Two areas within these networks respond to the change between perceptions. The superior temporal sulcus in the temporal lobe is responsible for interpreting positive events, and the inferior parietal lobule (IPL) for negative events. The two regions appear to inform each other which of them is active or inactive. In this way, it is believed, they determine whether positive or negative impressions dominate in an ambiguous situation, and relay that information to other areas of the brain. (www.mpg.de/10680717)



A matter of interpretation: The inferior parietal lobule (IPL) in the parietal lobe evaluates negative situations, while the superior temporal sulcus (STS) in the temporal lobe interprets positive events. Both areas are part of two neural networks that help the brain to evaluate its environment.

The Great Tit Fares Better in the Countryside

The birds have fewer and smaller offspring in cities



Great tits are evidently fans of country life: Although urban great tits begin to breed earlier, their broods are smaller and the fledglings weigh less than their counterparts in the countryside. According to researchers from the Max Planck Institute for Ornithology in Seewiesen, temperature, humidity, light and noise are not the reasons why rural birds have it easier – despite the fact that different values were measured between the city and the countryside for all four environmental factors. The study highlights just how difficult it is to precisely measure the impact of urbanization on natural ecosystems. (www.mpg.de/10708754)

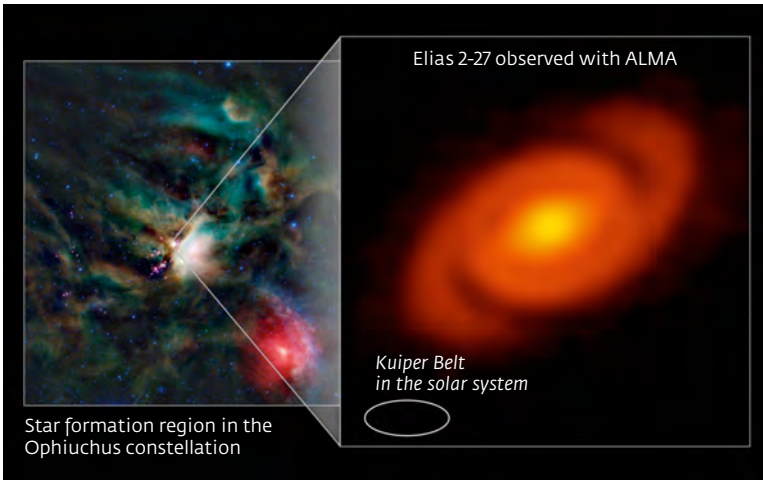
In focus: For the study, individuals with an interest in nature sponsored a nest box and used a webcam to observe its residents. The camera images were transmitted directly to the sponsors' mobile devices.

Photos and graphic: Ph. Sprach (top), NASA/JPL-Caltech/WISE team (bottom left), B. Saxton (NRAO/AUI/NSF), ALMA (ESO/NAO/NRAO), L. Pérez (MPIOR) (bottom right)

Spirals Assist in the Birth of Planets

Astronomers discover density waves in a protoplanetary disk around a star

A team of scientists headed by Laura Pérez from the Max Planck Institute for Radio Astronomy has discovered a striking spiral arm structure in the disk of gas and dust around the young star Elias 2-27, which is located around 450 light-years from Earth. They obtained the image with the world's biggest radio telescope, the ALMA in the Chilean Andes, which consists of 66 antennas. The spirals are either a result of the presence of young planets, or they create the conditions under which new planets form in the first place. The structure is made up of matter near the midplane of the disk, the region in which new planets can arise. The spirals can produce instabilities, leading to sub-regions with much higher density, and thus to the formation of planets. Previously, astronomers knew of density waves only from much larger objects: they normally occur in spiral galaxies. (www.mpg.de/10777685)



Where stars are born: The photo on the left is an infrared image of the Rho-Ophiuchi region, around 450 light-years away. The image on the right shows thermal dust emissions from the protoplanetary disk surrounding the young star Elias 2-27.

Warmer Mediterranean Turns the Sahel Green

Anthropogenic climate change helps fan the West African monsoon by carrying moisture from the Mediterranean



Climate change can have mixed consequences: it would appear that the warming of the Mediterranean region, which has brought greater heat and drought to the region over the past 20 years or so, has led to increased rainfall in the Sahel region. Researchers from the Max Planck Institute for Meteorology in Hamburg report that more moisture from the eastern Mediterranean is reaching the southern edge of the Sahara at the start of the West African monsoon in June due to higher sea temperatures in the Mediterranean. Moreover, according to the ongoing study, the future precipitation trend in the Sahel region will depend crucially on warming trends in the Mediterranean, particularly as compared with the tropical oceans. (www.mpg.de/10645369)

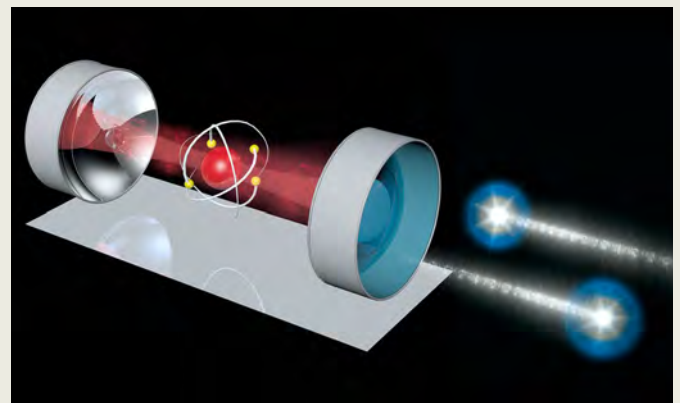
In the past 20 years, the Sahel has become greener as a result of the West African monsoon bringing more rain to the sub-Saharan region.

Quantum Logic with Light

A photon can switch another photon with the aid of a single atom between two mirrors

The Jedi in the Star Wars saga wage an impossible battle – not because of the superiority of the enemy empire, but because of the constraints of physical laws. Light-sabers don't clash and clang like metal blades: light beams simply don't notice each other. For a light beam to interact with another light beam, a relatively large optical component is required as a mediator, as well as a very intense light source. Researchers from the Max Planck Institute of Quantum Optics have now managed to bring two individual photons into contact with each other. They achieved this by allowing the two photons to interact with a single atom that they held suspended between two mirrors with the aid of a laser. In the process, the direction of oscillation of one photon changed depending on the direction of oscillation of the other. The researchers' experiments therefore not only solved the Jedi's prob-

lem, but also produced a photon switch that is suitable for use as a processor in future photon-based quantum computers. Single photons are particularly suitable for the job because they can be used to transmit quantum information over long distances. (www.mpg.de/10644678)

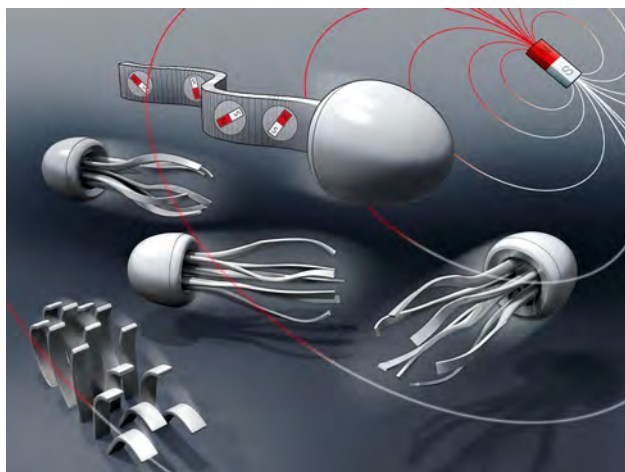


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A universal quantum gate: Max Planck physicists cause two photons (right) to interact with each other by using an atom in a resonator as a mediator. The resonator consists of two mirrors and a laser that suspends the atom between them.

Magnetically Driven Microrobots

Rubber strips that change shape in magnetic fields could serve as motors for tiny swimming robots

Microrobots could one day mimic the locomotion of spermatozoa and paramecia and swim through the human body, delivering drugs precisely where they are needed. Researchers from the Max Planck Institute for Intelligent Systems in Stuttgart developed magnetic rubber strips for such tiny robots that copy the swimming movements of natural flagella, cilia and tentacles. To achieve this, the silicone strips have magnetic particles embedded in them. The scientists use a magnetic field to control the complex movements of the biomimetic locomotor mechanisms. The magnetic field, in turn, is controlled by a sophisticated computer program. Driving microrobots indirectly in this manner is more effective than embedding magnetic particles in them and directly drawing them through a fluid with a magnetic field. Components that can be reshaped with a magnetic field could find applications in micro process engineering, in which chemical and physical processes are carried out on an extremely small scale. (www.mpg.de/10754617)



Magnetic cilia and tentacles: Using an external magnetic field and silicone strips containing magnetic particles, robots can be moved like jellyfish, bacteria or spermatozoa.

Loophole for Tumors

Cancer cells destroy blood vessel walls in order to escape from the bloodstream and form metastases

Many cancers become a mortal danger only if they form metastases elsewhere in the body. Such secondary tumors are formed when individual cells break away from the main tumor and travel through the bloodstream to distant areas of the body. To enter surrounding tissue, they must pass through the walls of small blood vessels. Scientists from the Max Planck Institute for Heart and Lung Research in Bad Nauheim and Goethe University Frankfurt have now shown that cancer cells kill specific cells in the vascular wall. The vascular wall cells themselves give the signal for their own death: they present a receptor molecule called death receptor 6 (DR6) on their surface. Contact with a cancer cell activates the receptor and kills the vascular wall cell. In this way, the cancer cell creates a passage out of the bloodstream. The researchers were able to reduce the spread of metastases in cancerous mice by blocking DR6 with an inhibitor. However, before the DR6 blockade can be used in cancer patients, it must be determined whether the results in mice can be transferred to humans and whether such therapy produces unwanted side effects. (www.mpg.de/10686146)

Graphic: Phil Loubere

Clichés about Nations Govern our Actions

Economic theories have generally ignored the influence of clichés on international cooperation. Scientists from the Max Planck Institute for Research on Collective Goods had 1,200 people from six countries interact with each other online. They presented the subjects with the prisoner's dilemma – a game in which the participants, who can't make any arrangements with one another, must decide whether to behave selfishly or cooperatively. The dilemma lies in not knowing what the other person will do, so the partners must try to assess the behavior of the other. If a player thinks their partner will behave selfishly, then they will likewise usually choose selfish behavior. If a player judges their partner to be cooperative, then they will likely also choose to cooperate. In the game, the only thing the players knew about their opponents was their nationality. The scientists also asked the participants to assess each other – and found that they were strongly guided by prejudices. Americans, for example, expected a high level of cooperation from Japanese but less cooperation from Israelis, and acted accordingly. Israelis, in turn, judged Americans to be cooperative and opted to cooperate themselves. The Japanese, on the other hand, tended to judge other nationalities pessimistically and therefore usually acted egotistically. Thus, the players often acted on the basis of stereotypes that proved to be wrong. (www.mpg.de/10746991)

The Cosmic Archaeologist

He loves basketball and literature, but his real passion is cosmology. **Joe Hennawi** uses telescopes and supercomputers to investigate the largest structures in the universe at the **Max Planck Institute for Astronomy** in Heidelberg – in a research group called ENIGMA. Their aim is nothing less than to unravel the mysteries of the cosmic web.

TEXT **THOMAS BÜHRKE**

Quite a few careers in astrophysics begin with the purchase of a telescope as a teenager. At night, the budding young researcher looks in amazement at the rings of Saturn and the mountains on the moon. For Joe Hennawi, it was rather a series of fortunate incidents that led him to astrophysics; he could just as well have ended up as a writer or a professional basketball player. He now leads a research group bearing the apt name ENIGMA at the Max Planck Institute for Astronomy. Six years ago he received the Alexander von Humboldt Foundation's Sofja Kovalevskaja Award, one of Germany's most prestigious and highly endowed research awards, and he has recently caused quite a stir with several of his discoveries. But first things first.

His office at the Max Planck Institute atop the Königstuhl hill in Heidelberg doesn't reveal anything special –

that is, if one ignores the hundred or so empty water bottles glinting in the sun on the window ledge. Astrophysics must make you thirsty. Joe Hennawi focuses on the structure of the universe and often has to cope with massive quantities of data that require efficient computer algorithms to interpret them. "Big data has become a fundamental issue in our field," he says, and adds: "I dedicate about a third of my time to theory, and the other two-thirds to observations using the largest telescopes in the world."

ENIGMA, the collective name of the 15 or so young people in his group, stands for Exploring the Nature of the Inter- and Circum-galactic Media. Even though the acronym is not self-explanatory at first glance, the research direction is clear: it's all about the gas that surrounds the galaxies and permeates the vast spaces in between them. It has a crucial impact on the evolution of the galaxies, our Milky Way included. This

gas forms a gigantic cosmic web between the galaxies, and its structure provides us with information about how the universe has evolved since the Big Bang. Hennawi focuses on the big issues in cosmology. But it all began on a rather modest and small scale.

His parents emigrated from Egypt to the US. As Christians – their name means "family of John" – they didn't have the easiest time in their home country. "But they also emigrated for economic reasons," says Hennawi, who was born in 1976 in Salinas, California, not far from Monterey. Both his parents have a business degree, and his father later opened his own shop, where Joe also spent a lot of time.

He received good grades in high school, but he didn't take even one physics course. "Sports was my main focus back then," he recalls. After high school, he didn't apply for a big university, choosing instead to go to a community college in Salinas that had a de-



"I'm sticking with cosmology for the moment," says Joe Hennawi, Research Group Leader at the Max Planck Institute for Astronomy in Heidelberg.



» Time and again, he thought about giving up [on physics]; he took a trip to Egypt to learn more about his roots. Ultimately, though, he fought his way through and obtained his master's degree.

cent reputation. Here, Joe enrolled in a broad range of courses, continued to play basketball, and even toyed with the idea of a professional career.

His physics teacher finally changed everything. "He was excellent and really inspiring, and we've stayed in contact and remain friends to this day." Joe said goodbye to his dream of being a basketball star and decided to study physics. And his parents? "They weren't too happy about physics. They would have preferred that I pursue a more pragmatic vocation, such as engineering," says Hennawi. His sister chose this path and is now an engineer. But Joe remained true to physics.

His good grades earned him a place at the renowned Stanford University – a huge opportunity. But he met with challenges early on: "I enrolled in a basic course on electromagnetism, and at the end of the first class I was complete-

ly frustrated: I thought, I don't know anything, I'm not well prepared for this." Time and again, he thought about giving up; he took a trip to Egypt to learn more about his roots. Ultimately, though, he fought his way through and obtained his master's degree.

THE OLDEST EVIDENCE FROM THE EARLY UNIVERSE

At Stanford he also became acquainted with Einstein's general theory of relativity, which would be a recurring theme in his subsequent work. He worked for a short time on the LIGO project – the detector involved in the spectacular discovery of gravitational waves in February 2016. "Perhaps I should have stuck with that after all," says Joe Hennawi with a grin.

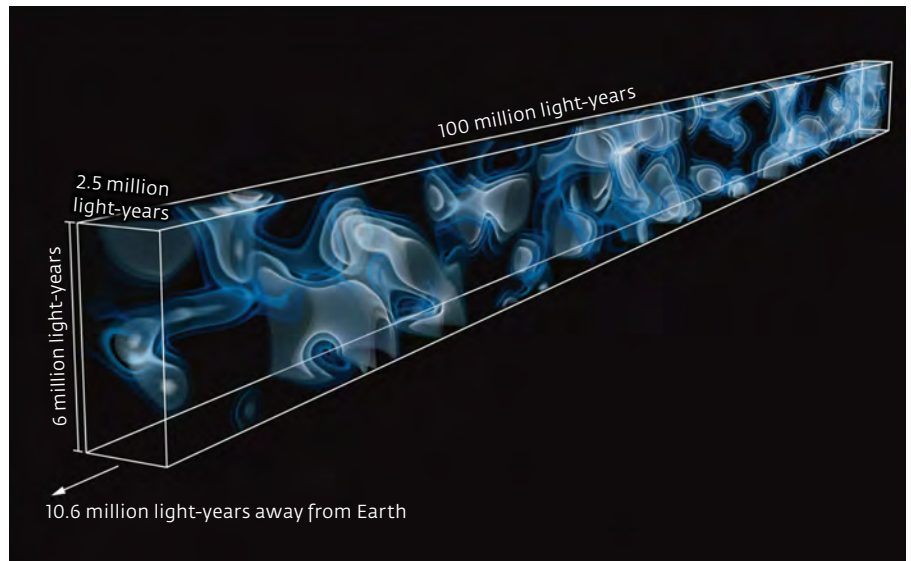
Offered a full scholarship, he moved to the equally renowned Princeton Uni-

versity. This is where Albert Einstein worked until his death, and where there was also a strong cosmology group. Joe Hennawi's doctoral supervisor, David Spergel, was working on observational data from a space telescope known as the Wilkinson Microwave Anisotropy Probe (WMAP), which was being used to investigate the cosmic background radiation. This radiation is considered to be the oldest evidence of the early universe – and it contains a plethora of information about the beginnings of the universe: groundbreaking cosmology in its purest form.

At Princeton, Hennawi worked on the theory of the background radiation, which again involves the general theory of relativity. The cosmic background radiation, relic radiation produced 380,000 years after the Big Bang, fills the entire universe and can be seen in all directions on the sky. It

Left page The universe on a computer: Joe Hennawi investigates the largest structures in the universe – on his laptop in a quiet corner of the Institute.

Right Cross-section through the past: Joe Hennawi and his team identified the hydrogen absorption lines of the cosmic web in the spectra of 24 faint galaxies and used them to reconstruct a three-dimensional map that shows a small part of the universe when it was not quite three billion years old. The lighter the color, the higher the density of the hydrogen gas.



thus traveled through the universe for almost 14 billion years before arriving at astrophysicists's telescopes. It went through a lot on this long journey: it traversed gas clouds, either inside galaxies or between them, and was deflected from its straight line of propagation by gravity, as predicted by Einstein's theory.

This cosmic background radiation is thus slightly distorted when it arrives on Earth; it is like looking at it through a pane of translucent glass. On the one hand, this is annoying, as it distorts the information from the early universe; but on the other hand, it also offers a unique opportunity to learn something about the galaxies and the intergalactic matter between them. And this is what Hennawi studied during his PhD at Princeton.

As his doctoral studies drew to a close, he received his first opportunity to undertake astronomical observations himself. "But I wasn't observing at a telescope perched on a mountaintop – I was in the basement of our astronomy department," he remembers, somewhat wistfully. Hennawi operated the telescope in New Mexico via remote

control. But things are different now. Today, Joe Hennawi travels to the biggest observatories on Earth in Hawaii and Chile.

SWIRLING GAS HEATS UP TO SEVERAL MILLION DEGREES

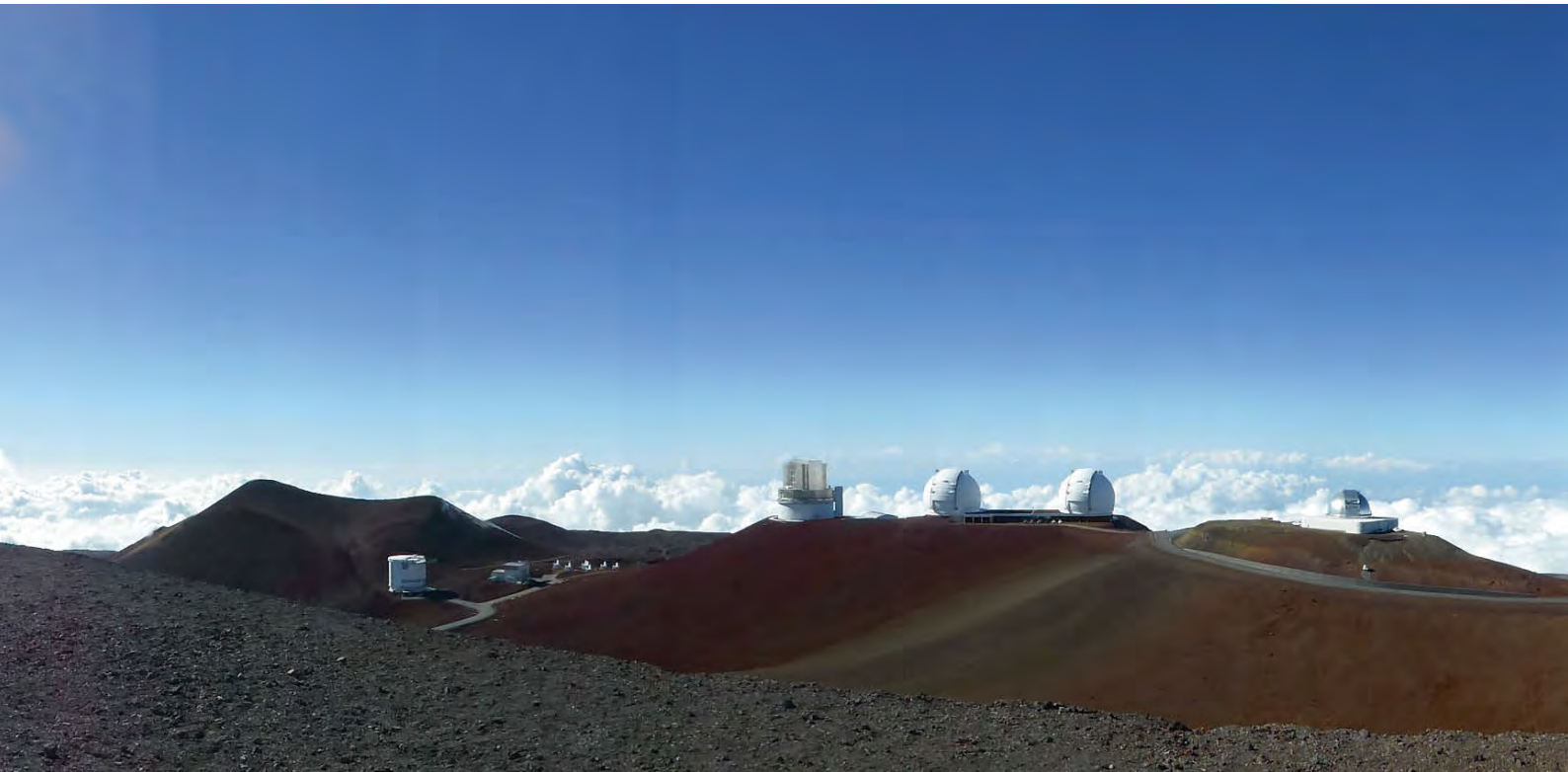
Even though the telescope he used in New Mexico was on the small side, he still discovered celestial bodies that still occupy his attention today: quasars. When they were discovered in the 1950s, they were known as quasistellar objects, as they appeared to be point-like, similar to stars. However, a great many other characteristics indicated that they couldn't be stars. Astronomer Maarten Schmidt solved the puzzle in 1963, and showed that quasars are actually among the brightest and most distant objects in the known universe.

A theory soon emerged about how the huge amounts of radiation could be produced. The idea is that quasars reside at the center of young galaxies that possess a supermassive black hole. These attract gas from their surroundings, which accumulates in a large disk around the black hole before gradual-

ly plunging in – like water gurgling into a drain and disappearing. As it falls onto the black hole, the gas heats up to several million degrees and shines incredibly brightly. A quasar shines a thousand times more brightly than the light emitted by everything else in the galaxy – up to hundreds of billions of stars – combined.

This explanation of quasars is accepted as standard today. And since our current knowledge states that there is a central, supermassive black hole at the center of almost every galaxy, this suggests that every galaxy must also be a quasar – but this is by no means the case. Quite the contrary: quasars tend to be extremely rare, because the quasar activity lasts for only around ten million years. Compared with the typical age of a galaxy of more than ten billion years, this is a very short period of time. It is therefore an improbable stroke of luck if astronomers see a galaxy when it is actually in its quasar phase.

Joe Hennawi continued his work on quasars at the University of California, Berkeley from 2004-2009, where he received a prestigious Hubble Fellowship



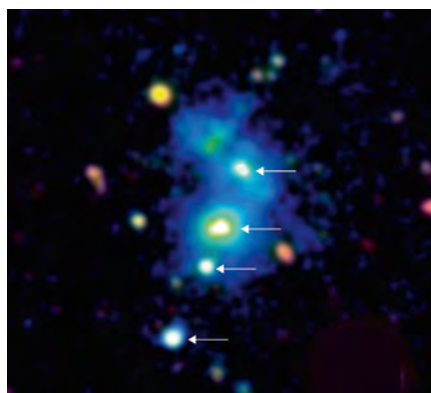
Top Above the clouds: Joe Hennawi uses data from the world's largest telescopes for his work – like these on the summit of Mauna Kea in Hawaii. The two white domes (image on this page) conceal the two Keck telescopes, each with mirrors measuring ten meters in diameter.

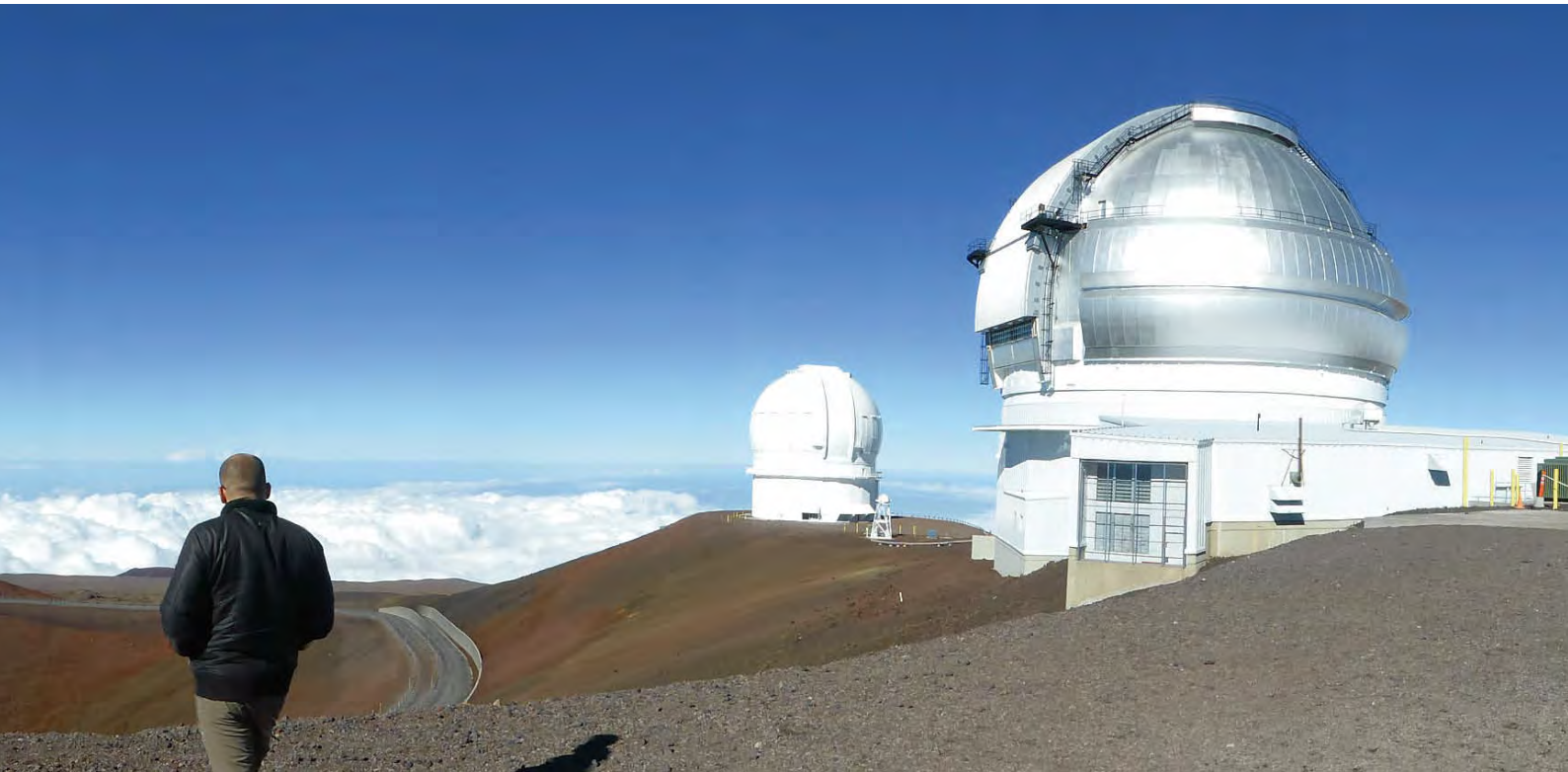
Below Rare shots: Left, a section of the cosmic web (turquoise) stretching over roughly two million light-years, which was observed in the immediate vicinity of the quasar UM 287. The gas glows thanks to the same effect to which fluorescent tubes owe their light. Somewhat smaller, namely around one million light-years, is the nebula in which the four quasars (arrows) in the photo on the right are embedded. The quartet is a rarity; its light needs ten billion years to reach us.

and then a National Science Foundation Fellowship to continue his groundbreaking research. “This is where I learned to handle big data,” he recalls. Big data has become a fundamental theme in modern astronomy and astrophysics, as many telescopes record massive amounts of data from large areas of the sky night after night, detecting copious numbers of faint stars and galaxies.

One of these surveys, the Sloan Digital Sky Survey (SDSS), has been running since the year 2000 at the Apache Point Observatory in New Mexico. It uses a custom-designed telescope and has so far imaged billions of celestial objects covering about half of the night sky through multi-color filters, and recorded more than three million spectra of these objects. The result is the most detailed three-dimensional map of the universe ever made. The Max Planck Institute for Astronomy has been involved in the SDSS project since it began, and Joe Hennawi mines this treasure trove of data for his research.

After five years at Berkeley, Hennawi moved to the Max Planck Institute for Astronomy in Heidelberg in 2009. He initially found the charming town a bit small, and chose to live in the bustling metropolis of Frankfurt in-





»» Cosmological models predict that the universe is permeated by a complex web-like network of filaments, with giant voids or holes, similar to Swiss cheese.

stead and commute. From the beginning, it was important to him to learn German, and he enrolled in a two-year German language course that the Humboldt Society offers its award recipients. Eventually Hennawi can even read German literature, from the likes of Max Frisch and Hermann Hesse to Franz Kafka. “But I find Günter Grass too difficult to read in German,” he says, adding “If I hadn’t become an astrophysicist, I probably would have gone into creative writing.”

After less than a year at the Max Planck Institute, he was awarded the Humboldt Foundation Sofja Kovalevskaja Award. He used the prize money of almost 1.5 million euros to expand his research group. Scientific success soon followed.

Around three years ago, his team, together with colleagues from the University of California, Santa Cruz, discov-

ered a quasar surrounded by an unusual nebula. One of its peculiarities was that it extended over roughly two million light-years, so its light couldn’t be attributed to the galaxy hosting the quasar at its center. “We succeeded in detecting part of the cosmic web,” explains Joe Hennawi (MAXPLANCKRESEARCH 2/2014, p. 41).

Cosmological models predict that the universe is permeated by a complex web-like network of matter with voids or holes, similar to Swiss cheese. Its walls are filaments of hydrogen gas and dark matter. Galaxies such as our Milky Way, and also quasars, reside primarily at the nodes connecting the filaments of this web. But the gas in this so-called cosmic web is so rarefied that it was never possible to image it directly before. In the case of Hennawi’s nebula, however, the quasar acts like a flash-light that excites the surrounding hy-

drogen gas to emit light, thus making part of the web visible. The editors of the journal *PHYSICS WORLD*, published by the British Institute of Physics, chose this discovery as one of the “Top Ten Breakthroughs” of 2014.

THE QUASAR LIGHT TRAVELED TEN BILLION YEARS

In 2015, Hennawi and his colleagues pulled off another feat: they chanced upon a quasar quartet, which was similarly surrounded by a giant nebula of hydrogen gas (MAXPLANCKRESEARCH 3/2015, p. 44). To understand the excitement this generated, it must be understood that, although we now know of around half a million quasars, they are spread over vast regions of the sky. It is extremely unusual to find two quasars very close to each other. We currently know of only a hundred quasar pairs,



Research dialog: Joe Hennawi discusses the latest results with his PhD student Anna-Christina Eilers. What fascinates him about cosmology is that it is cleanly and clearly described by the equations of the general theory of relativity.

and just a single quasar triplet. “The probability of a chance coincidence of four quasars in such a small region of space is one in ten million,” explains Hennawi, who hence named the quartet the “Jackpot Nebula.” Finding this constellation was by no means a mere stroke of luck, as the surrounding region of space also contains several hundred times more galaxies than the researchers expected. They had stumbled upon a rare massive structure in the early universe.

This discovery also attracted significant attention. The US magazine *ASTRONOMY* ranked it fourth in its top five discoveries – just behind the Horizon probe flyby of the dwarf planet Pluto. To put Hennawi’s discovery into perspective, consider that the light from these quasars had been journeying through space for ten billion years before it reached us. This allows researchers to see the universe as it looked more

than ten billion years ago, less than four billion years after the Big Bang. In a way, the astronomers are doing cosmic archaeology.

USING NORMAL GALAXIES AS COSMIC LIGHTHOUSES

But there is yet another way of getting to the bottom of the cosmic web, which is spread out over billions of light-years. It bears a remote resemblance to computer tomography, so-called CT scans, in which X-rays are used to scan the inside of the human body from different directions.

To achieve this, the astronomers exploit the fact that the light – from a distant quasar, for example – traverses the walls and filaments of the cosmic web several times as it journeys toward us. Each time it does so, the hydrogen gas absorbs a small amount of the light. If the quasar light is dispersed into its

spectral components, the hydrogen absorption appears as a dark line in the spectrum at a very special wavelength.

The fact that space is continuously expanding causes this hydrogen line to shift toward ever longer wavelengths the further the absorbing cloud is away from us. If the quasar light has traversed ten such clouds on its journey, then there will be ten absorption lines at different wavelengths; their positions in the spectrum can be used to determine the distance of the cloud. It is thus possible to determine the spatial distribution of the cosmic web and the density of the hydrogen gas that permeates it.

Since quasars are rare objects distributed all over the sky, aside from the few rare exceptions of multiple systems, researchers can study only single points through the web. However, it would be a different story if one were to use, not quasars, but the much more abundant normal galaxies as the “cosmic light-

houses.” This seemed to be impossible, because galaxies at these enormous distances are extremely faint. It thus came as a tremendous surprise when Hennawi and his postdoc Khee-Gan Lee tackled this project – with success.

Using the giant 10-meter reflecting telescope known as Keck I on the summit of Mauna Kea in Hawaii, they recorded spectra from 24 faint galaxies and showed how one could identify the hydrogen absorption to construct a map of the cosmic web. “This is the first time we’ve been able to reconstruct a three-dimensional map of a small part of the universe that stretches back to a time when the universe wasn’t even three billion years old,” explains Joe Hennawi. This project to map the cosmic web continues. Since their groundbreaking discovery, the scientists have extended their method to large volumes of the universe using a hundred galaxies.

What’s next for Hennawi after so many success stories? “I’m sticking with cosmology for the moment,” he

says. “The Universe is a well-defined physical system that is cleanly and clearly described by the equations of the theory of relativity, but it still offers enough puzzles to keep me busy.” The nature of dark matter could be the next frontier: “It turns out that observations of the cosmic web can be used to con-

strain its quantum mechanical properties,” says the Heidelberg-based Max Planck researcher. “The role massive neutrinos play in forming structure in the universe also interests me.” In other words, the really big questions. Which, of course, doesn’t leave much time for basketball. ◀

GLOSSARY

Cosmic background radiation: Also known as the cosmic microwave background or CMB, as it is observed in the microwave range. It formed around 380,000 years after the Big Bang, when the universe became transparent, protons and electrons bonded together, and light particles (photons) were henceforth able to fly unhindered through space. The background radiation bears the signature from the era in which it was formed and is thus a valuable tool for studying the structure and physical properties of the very young universe.

Wilkinson Microwave Anisotropy Probe: The US satellite, WMAP for short, was launched in 2001 and sent data to Earth until 2010. Its task was to map the irregularities in the cosmic background radiation. Researchers used the measurements to determine the composition of the universe: 4.6 percent normal matter, 23 percent dark matter, and 72 percent dark energy. These values were corrected slightly by its successor, the Planck satellite.

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Microboats to the Rescue

Some medical treatments would be more efficient if medication could be transported via a tiny robot directly to the diseased area. **Peer Fischer** and his colleagues at the **Max Planck Institute for Intelligent Systems** in Stuttgart are developing microswimmers and nanoswimmers that are expected to one day make this possible.

TEXT **KARL HÜBNER**

A simple DIN A4 sheet of paper hangs beside the lab door. It reads: “Please don’t clean.” That should please the cleaning staff.

And the lab users are much more relaxed because they know that if no one is clearing away objects and wiping the tables, nothing important can go missing. That’s how it is when researchers work with objects that can’t be seen by the naked eye. This explains why the “Micro, Nano, and Molecular Systems” Research Group at the Max Planck Institute for Intelligent Systems in Stuttgart is protecting at least one of its labs this way.

The group is led by Peer Fischer, who is also a professor at the University of Stuttgart. In recent years, his research has resulted in a small fleet of miniature vehicles – microstructures

and even nanostructures that can move through liquids in various ways in a controlled manner, and that many already describe as tiny robots.

NO LIMIT TO HOW SMALL MACHINES CAN BE MADE

When Fischer describes the work his roughly 20-person team performs, he is happy to draw on a vision originally set out by Richard P. Feynman almost 60 years ago. On December 29, 1959, the American physicist delivered a lecture entitled “There’s Plenty of Room at the Bottom.” By this, Feynman meant that there is really no limit when it comes to designing the tiniest possible engines, machines and other objects. With that, he fired the starting shot, as it were, for nanotechnology, long before this term even existed. >

It’s simply a matter of principle: Bacterial motor systems, for example, can’t be replicated exactly for artificial microswimmers and nanoswimmers. The researchers in Stuttgart demonstrate this with models that they equip with batteries, engines and circuit boards. Because there is no room for these things in tiny robots, they implement biological drives differently, such as in the case of the magnetically driven nano-screw (far right).



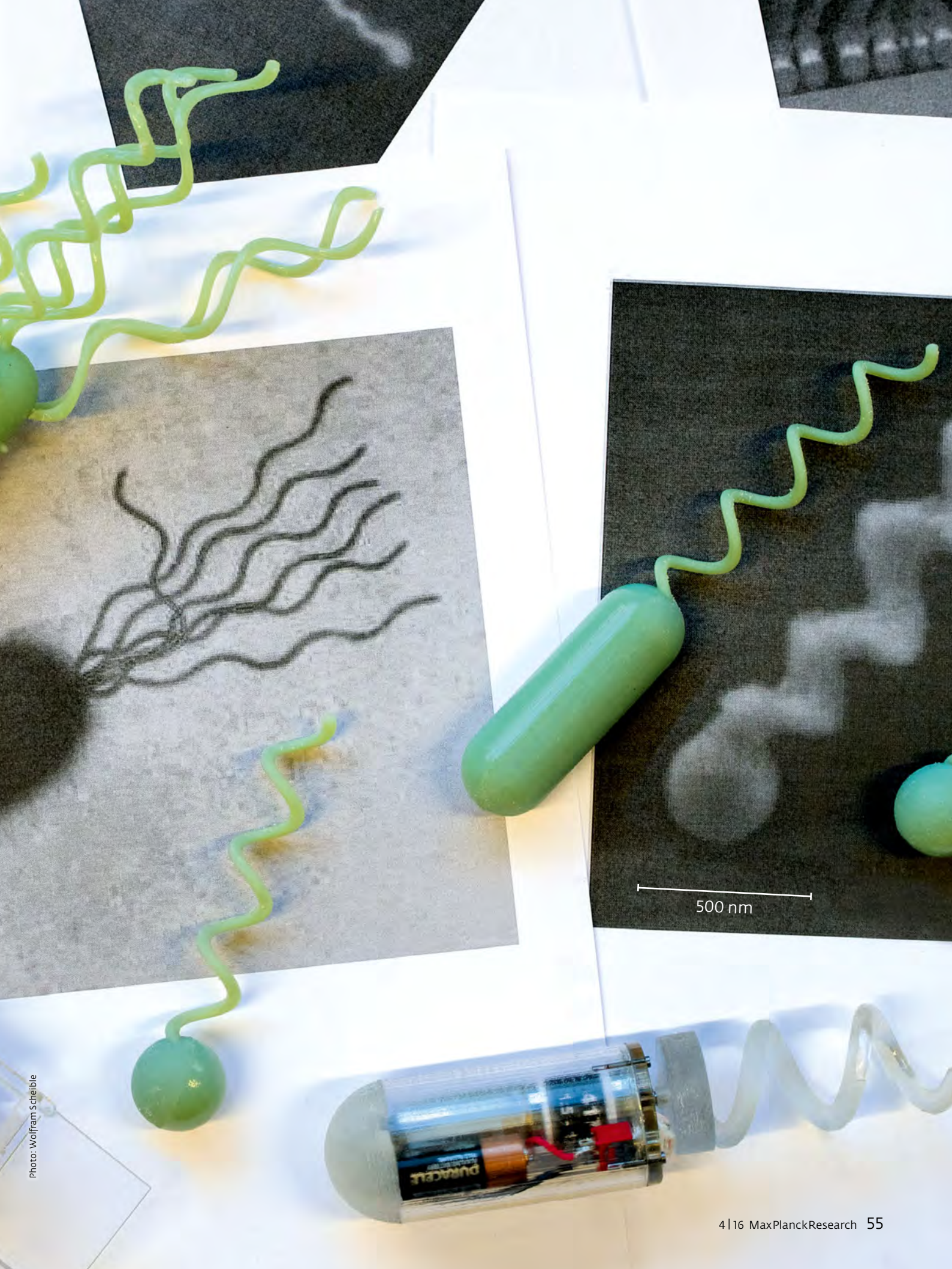
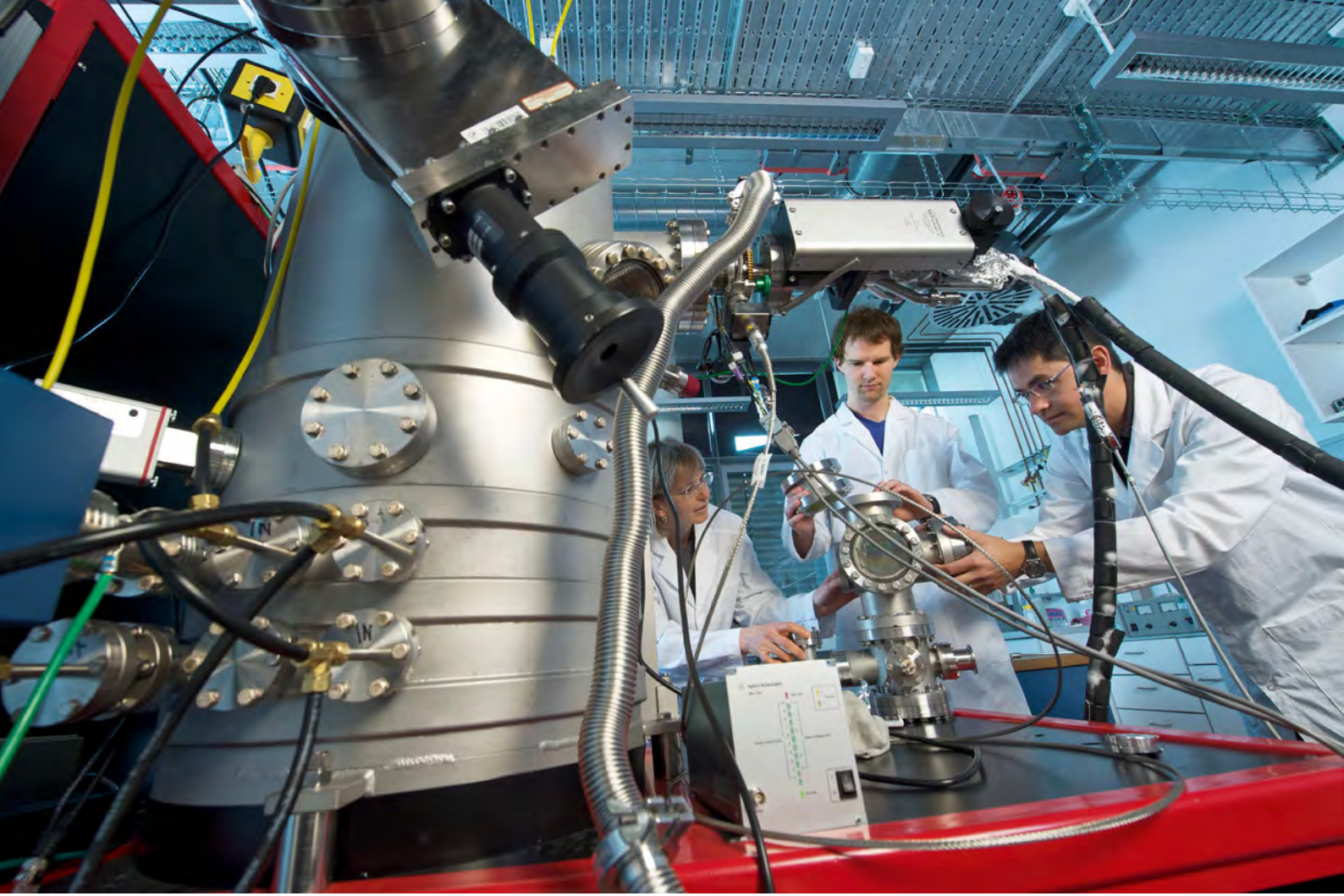


Photo: Wolfram Scheible



A production facility for nanorobots: The Max Planck researchers Conny Miksch, John Gibbs and Andrew Mark (left to right) examine the vacuum system in which complex nanostructures are evaporated layer by layer onto a silicon wafer.

And Feynman had very concrete ideas: “Although it is quite a wild idea, it would be interesting for surgery if you could swallow the surgeon. You put the mechanical surgeon inside the blood vessel and it goes into the heart and ‘looks’ around. [...] It finds out which valve is faulty and takes a little knife and slices it out.” This idea also inspired filmmakers. In the 1966 Hollywood movie *Fantastic Voyage*, a tiny submarine boat with a miniature-sized emergency crew on board ventured into the veins of a man to remove a blood clot in his brain.

Ideally, the miniature vehicles in Peer Fischer’s research group will also one day also be able to move through tissue, mucous membranes, the blood-brain barrier and the eye’s vitreous humor. These will hardly have miniature surgeons on board, but will perhaps carry, instead, pharmaceutical drug molecules, genetic blueprints or remotely controlled surgical instruments.

Nevertheless, Fischer isn’t too happy about having his work associated with *Fantastic Voyage*. According to him, too much of the film is scientifically “extremely dubious.” For example, “the active and controlled movement” of the mini submarines through the blood vessels. The top speed of 15 knots, which is equivalent to 30 kilometers per hour, also makes Fischer smirk: such a speed is very unrealistic for a miniature submersible vehicle.

A MEXICAN WAVE ON THE CILIATE

Hollywood doesn’t need to concern itself with the physical details of the micro world – with the fact that, for instance, small particles experience a high level of friction while their “inertia [is] of relatively no importance,” as Richard Feynman phrased it in his lecture. High friction in combination with low inertia simply means that a vehicle immediately comes to a stop as soon as

the engine is cut. After taking a stroke, a human swimmer glides through the water for a while due to inertia. However, according to Peer Fischer, a bacterium whose propulsion stops moves just one-tenth of a nanometer further before it comes to a halt, if one neglects Brownian motion. A bacterium swimming in water is like a human trying to swim through tar.

And yet single-celled organisms have clearly developed techniques for actively moving in various fluids. Many bacteria have a rotating flagellum that propels them. A sperm, on the other hand, makes a sort of whipping movement with its tail, which helps it to push off from its environment.

Ciliates have mastered another technique. These protozoa are covered with countless tiny hairs that move in an elaborately choreographed sequence. The tiny hairs make synchronized movements that somewhat resemble our arms when doing the breaststroke.

» Fischer's group is currently concerned primarily with finding and testing drive principles for the microstructures.

Together, all the hairs perform what looks like a Mexican wave that runs along the entire body of the ciliate, propelling it forward.

It is precisely this complicated mechanism that inspired Peer Fischer and his colleagues to create a biomimetic microswimmer. It quickly became clear that it wouldn't be possible to produce an exact artificial copy. "After all, there is no electronic control system or even a battery that would be small enough to propel structures the size of an individual tiny hair," explains Fischer. "So we try to understand the essence of the principle, simplify it, and then apply it with all the resources available to us."

In the lab in Stuttgart, the biological template, the ciliate protozoa, became a one-millimeter-long cylinder made from a special material known as a liquid crystal elastomer: a plastic that exhibits the characteristics of both a liquid crystal and an elastic solid. "It's a type of molecular muscle in which individual sections expand as soon as they are exposed to light of a certain wavelength," explains Fischer.

Specifically, this means that the cylinder expands at the places where the researchers in Stuttgart expose it to green light. When the light disappears, these areas contract again. In their experiments, the researchers use a complex mirror system to project stripes of green light onto the tiny cylinder. The ultra-thin strips of light cause wave-like rings to travel through the vehicle, similar to the process of peristalsis that occurs in earthworms. And just as an earthworm pushes the earth behind it, the pulsating cylinder pushes past the surrounding water/glycerol mix and

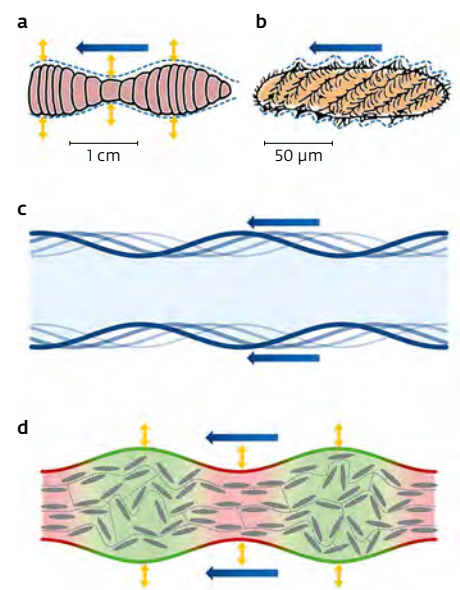
moves forward, traveling at a speed of around one centimeter per hour.

Of course the real ciliate moves considerably faster, but this is due to the fact that it simply sends many more waves over its surface per second. In any case, the researchers managed to transfer the movement principle to their microswimmers. What's more, they can use their special mirror to vary the light profile any way they want, and thus also change the direction of movement of their cylindrical submarine body – in this way, they made it swim along defined trajectories, for instance.

A MICRO-SCALLOP WOULD MAKE NO HEADWAY

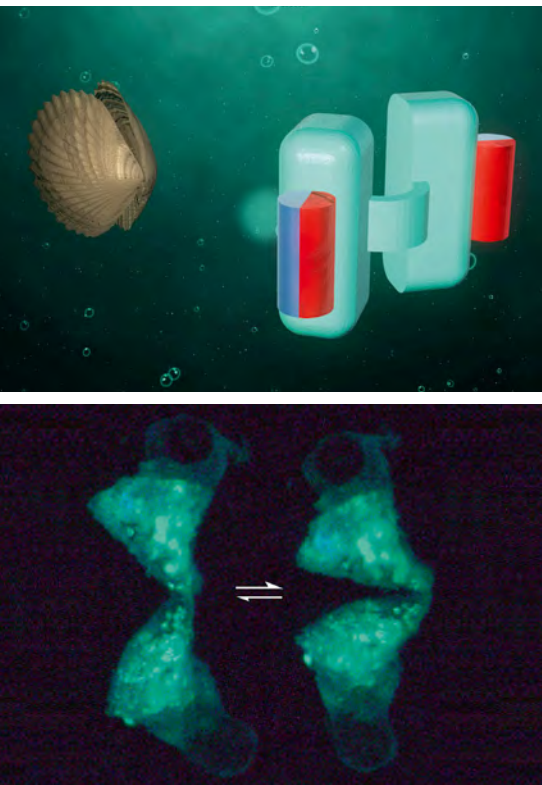
"That was the first time ever that an artificial microswimmer was able to use only shape changes to power itself without any external mechanical or magnetic forces having to be applied," says Peer Fischer. The tiny swimming robot needed only to be exposed to light. "In order to use such light-activated, liquid crystal elastomer constructs, they would perhaps one day be attached to the ends of glass fibers," says Fischer. In such cases, instead of acting as artificial microswimmers, they would act as artificial muscles that could move soft robot arms, for example at the end of an endoscope. But that's still in the distant future. At the moment, Fischer's group is concerned primarily with finding and testing principles to actuate and power microstructures.

The researchers even worked on a particular form of motion that shouldn't work for swimmers at low Reynolds



Modeled after nature: An earthworm (a) uses peristalsis to generate a wave on the surface of its body (c) in the same way a ciliate (b) moves the tiny hairs on its surface in a coordinated manner. The researchers in Stuttgart implement this principle by projecting stripes of green light onto a cylinder of a liquid crystal elastomer, which expands at the illuminated locations (d).

» Finding drive techniques for tiny artificial swimmers is a challenge for the researchers in Stuttgart. Another challenge they face is fabricating microswimmers.



Modeled on the scallop: Peer Fischer's team designed a microswimmer whose two halves are joined by a hinge and fitted with magnets (top). By opening and closing the two halves in a magnetic field (bottom), the researchers move the micro-scallop through biological fluids.

numbers: that of the scallop. The scallop swims through water by opening and closing both halves of its shell in a uniform motion. Scallops are a few centimeters in size and this technique works perfectly for their dimensions. The smaller a scallop is, however, the more friction becomes an issue. The viscosity of the water then seems to them to increase. The movements resulting from the uniform opening and closing of the shells ultimately cancel each other out – and a microscopic scallop would make no headway at all. Edward Purcell formulated this relationship in a rule that is named after this bivalve mollusk: the scallop theorem.

DIFFERENT THAN WATER: BIOLOGICAL FLUIDS

This rule applies not only to the opening and closing of two scallop shells, but very generally to mirror-symmetrical movements in extremely viscous environments. The microcosm of nature thus contains exclusively asymmetrical powering techniques, such as the rotating bacterial flagellum or the movements of tiny hairs on a ciliate.

Nevertheless, Fischer's group had set out to propel microswimmers using a mirror-symmetrical motor function, as the corresponding motor systems are usually based on simpler mechanisms and are easier to create. The researchers saw an opportunity for a symmetrical drive, because many biological fluids behave differently than water. "In synovial fluids, or vitreous humor in the eye, for example, the hyaluronic acid molecules are arranged in network-like structures, and this is precisely why the viscosity can change,"

explains Peer Fischer. As soon as a microswimmer moves around in these gel-like structures, the viscosity decreases because it breaks up the network. However, if the microswimmer persists, the bonds between the molecules are immediately reestablished. It is therefore possible to subvert the scallop theorem in such fluids.

Fischer's team demonstrated this for the first time in 2014: the researchers designed a 0.3-millimeter scallop-like body in which the two shells were connected by a hinge. They attached micro-magnets to the shells. When the scientists exposed the micro-scallops to an external magnetic field, the shells closed. When they removed the magnetic field, a sort of resetting mechanism in the hinge opened the artificial scallop again.

"The key is to open the shells much faster than we close them," explains Fischer. "This temporally asymmetric movement cycle results in the surrounding fluid being less viscous during the opening process than during the slow closing process." The scallop thus covers a greater distance when the shell is opening than when it is closing. The bottom line is that it makes progress – but only in liquids that act like a synovial fluid, the vitreous humor, or many other biomedically relevant fluids.

Finding drive principles that propel tiny artificial swimmers is a challenge for the researchers in Stuttgart. Another challenge they face is fabricating microswimmers like the tiny magnet-driven scallops in the most simple manner feasible. Their shells should be as thin as possible, but at the same time, they must be robust enough to withstand



Dust obstructs: In the clean room, the researchers use photolithography to create microstructures, such as the micro-scallop. It is crucial that they avoid even the tiniest impurities in the air.

the constant opening and closing in a relatively viscous environment. The researchers ultimately chose to make the micro-scallop from a solid siloxane polymer. This material was used in a 3-D printer to build the tiny structure, including the hinge, which was just 60 micrometers thick, or roughly the diameter of a human hair.

Creating the delicate copy of the scallop required great precision, but producing the smallest-ever vehicle in the Stuttgart fleet was even more difficult. This is a 400-nanometer-long screw made from quartz glass and nickel. The corkscrew-like spiral strand is just 70 nanometers thick – almost 1,000 times thinner than a human hair. It was only thanks to a process the researchers had developed themselves (see box at right) that they ultimately managed this complicated feat.

There is a simple reason why the researchers in Stuttgart are even puzzling over vehicles that are smaller than any

DESIGNING AND BUILDING NANOCOMPONENTS TO SPEC

It's not exactly an everyday achievement to manufacture high-precision components in the nanometer range, such as the corkscrew-like nano-screw. The Max Planck researchers in Stuttgart build such nanostructures layer by layer. They first cover a silicon wafer with a dense grid of gold dots measuring just eight nanometers in diameter. They position the wafer in a vacuum chamber in which they evaporate the desired materials. The substances then make their way to the wafer, which the researchers position in such a way that the particles can't reach the wafer surface, but only the gold particles, and are deposited there. (Just like the slanted rays of the evening sun in the mountains illuminate only the mountain ridges and peaks, but not the valley floors.) In this way, fine, clearly separated structures grow.

By rotating the wafer in various directions during the deposition process, the researchers can also generate complex geometries – they just have to ensure that the evaporated substances don't reach the wafer surface. By continuously rotating the wafer, they create the corkscrew-like nano-screws. When they tilt the wafer abruptly, the evaporated structure produces zigzag shapes. Since the structures grow atomic layer by atomic layer, the Stuttgart-based researchers can interrupt the process at any time and continue with another material. In this way, they can, for example, integrate magnetic nickel into a nanostructure that otherwise consists of silicon dioxide or titanium dioxide.

»» A microswimmer was successfully maneuvered through a viscous biological medium for the first time.



An opener for the stomach lining: The researchers in Stuttgart coated the quartz glass corkscrew-shaped micro-screw with enzymes that are used to liquefy the mucous locally, allowing the vehicle to swim through this gel-like network.

bacterium: they are looking for a swimming device that is small enough to swim through the three-dimensional hyaluronic acid network without having to break it apart. “So of course a swimmer must be smaller than the molecular mesh size of these networks, which is a few hundred nanometers,” says Fischer.

Once again, the researchers used a template from nature for their screw-shaped design. This time they used the bacterial flagellum, which works just like a corkscrew except that the microbes bore through fluids instead of through cork. That is precisely what the nano-screw from Stuttgart can do, too. The necessary rotation is ensured by an external magnetic field that acts on the nickel in the screw.

The researchers placed their nano-swimmers in a model fluid composed of water and hyaluronic acid, applied the rotating magnetic field and – were delighted. Using a microscope, they were able to watch how effortlessly the little screw pushed its way through. That this really was due to the tiny size of the vehicle was proven by running a comparison with a micrometer-scale screw, which got undeniably stuck after just a few rotations.

A MICROPROPELLER THAT LIQUEFIES MUCOUS

Slipping through the meshes is one way of penetrating a tightly woven molecular network. However, the scientists in Stuttgart had another idea: they wondered whether it would be possible to simply chemically dissolve the gel-like structure – essentially to liquefy it. This could be interesting, for instance, for using a swimming vehicle to transport drugs through the mucous membrane of the stomach, intestine or lungs directly to the diseased area.

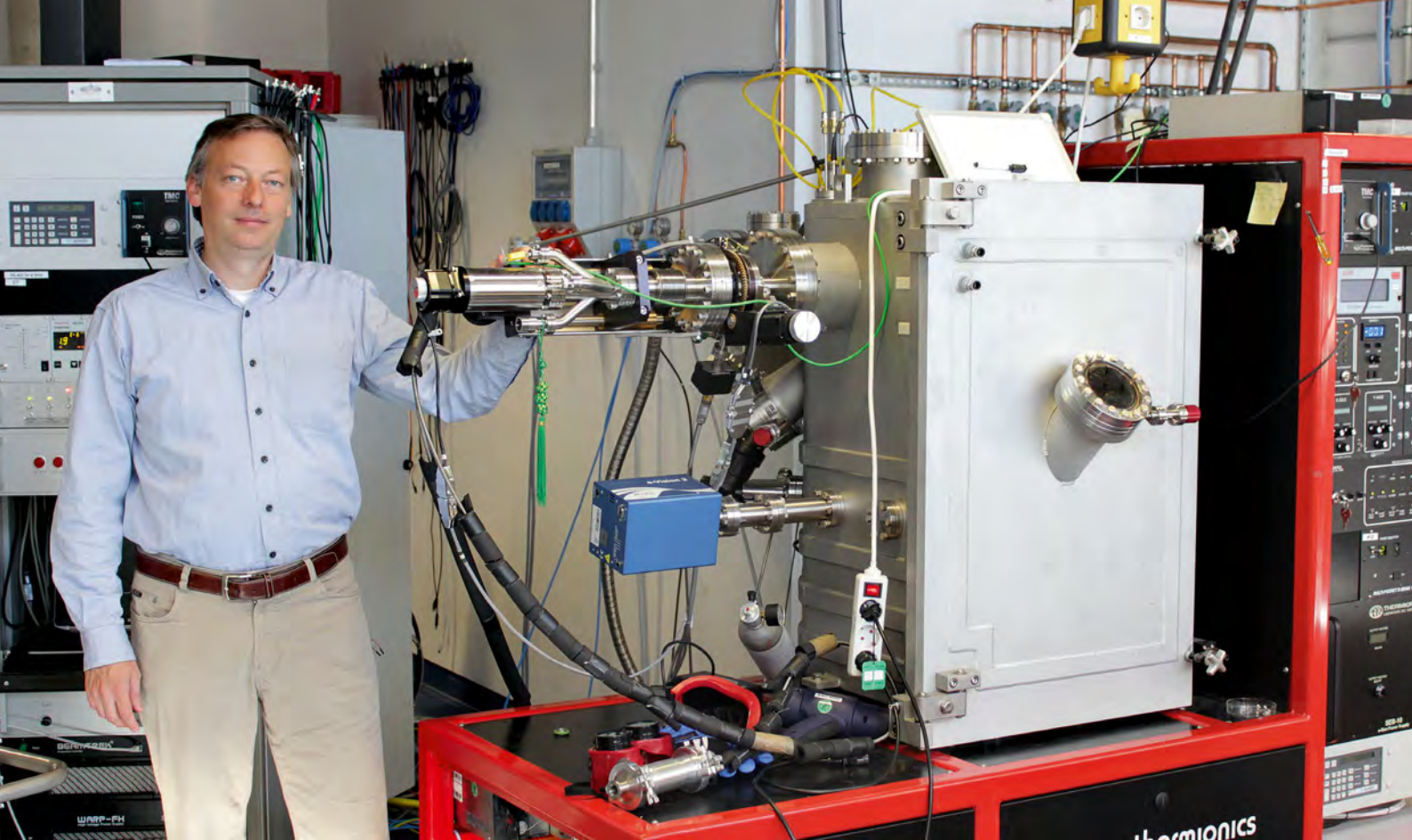
In order to create a tiny submarine that liquefies mucous, once again, a glance at nature helped the researchers. A bacterium known as *Helicobacter pylori* provided the crucial hint. Anyone who has heard of this bacterium certainly wouldn’t associate it with anything positive: researchers have known for about 25 years that *H. pylori* can cause inflammation and ulcers in the human stomach wall. It manages to make its way through the stomach lining by secreting an enzyme known as urease. This enzyme breaks down the urea that is present in the gastric fluid. In the process, ammonia is released – a

base that increases the pH value locally in the otherwise acidic milieu of the stomach. When this happens, the gel-like network of molecules in the stomach lining is broken up, and bacteria can swim through it.

Fischer’s team simulated this effect and designed a glass screw – similar to the previously mentioned nano-screw, only bigger. The researchers bound urease enzymes to the thread of the screw. This swimmer also contained some nickel so that it would rotate when a magnetic field was applied. The team finally tested this enzyme-coated microrobot in a milieu of pig stomach lining – and was actually able to pass it through the lining. It was another premiere: “A microswimmer was successfully maneuvered through a viscous biological medium for the first time,” says Peer Fischer, visibly pleased about the result.

The urease example shows that chemistry, too, offers a box of tricks that can open the door to opportunities for the movement of microswimmers. The scientists in Stuttgart want to make even greater use of it in the future. They plan to develop miniature vehicles that autonomously generate their own propulsion. In all previous projects, the researchers had to use external means to move the submarines, whether magnetic fields or light. “If we could equip our nanorobots with a chemical fuel, then they would have an engine on board, so to speak,” says Peer Fischer.

An initial approach has already been made: a microparticle that has two faces. The surface of one half is coated with a catalyst, while the surface of the other half isn’t. This Janus-head-



At the helm of nanoproduction: By tilting and rotating a silicon wafer in the vacuum unit when evaporating material onto it, the researchers generate nanostructures in the form of screws or zigzag lines. Peer Fischer holds the manipulator they use to adjust the wafer.

ed particle propels itself through a fluid containing a substance in which the catalyst triggers a chemical reaction. This chemical reaction changes the concentrations of the substances in the fluid in the environment of the microparticle half with the catalyst, creating a difference in concentration compared with the environment of the other microparticle half.

“As in the case of osmosis, the system wants to balance out this difference in concentration,” explains Peer Fischer. This means that fluid moves along the microparticle, generating a force in the process, and moves the microparticle forward in parallel with the concentration gradient. Fischer and his team would now like to transfer this principle to biological environments and replace the metallic catalyst with suitable enzymes. The end result could be a sort of biological self-driving chemotaxi. And when such a vehicle is one day roaming about the lab in Stuttgart, the cleaning staff will occasionally have to stay out again. Better safe than sorry. ◀

TO THE POINT

- **Microrobots and nanorobots that can be maneuvered through the body and transport active substances to the diseased area could make medical treatments more efficient.**
- **Max Planck researchers in Stuttgart are designing drive systems for such tiny vehicles, and developing methods for producing them.**
- **To do this, they simulate mechanisms from nature, such as the concentrated movement of tiny hairs on a ciliate, or the mucolytic effect of *Helicobacter pylori*, and implement them with technically feasible means.**

GLOSSARY

Liquid crystal elastomer: A plastic whose shape can be changed elastically and that exhibits the structure of a liquid crystal. Liquid crystals are liquid, but their molecules don't form a disordered structure like liquids, but rather arrange themselves at least in one dimension with a preferred orientation, making them resemble crystals.

pH value: A measure of how acidic or basic a liquid is. The pH value is low in an acidic milieu and high in a basic milieu.

Scallop theorem: According to this rule, in most liquids, such as water, very small swimming bodies can't be propelled using symmetric movements. For example, they can't move in the same way a scallop does. This is because the effect of friction in nanoswimmers and microswimmers is much greater than the effect of inertia, with the result that symmetric movements move the swimmer exactly the same distance forward and backward. However, this rule can be subverted in gel-like biological fluids.

Hot Air in the Orient

The Middle East and North Africa are currently being rocked by armed conflicts and political crises. But even if these were to be resolved, many people there will likely be forced to leave their homes in the coming decades. **Jos Lelieveld**, Director at the **Max Planck Institute for Chemistry** in Mainz, and his colleagues are predicting that the region will see dramatic climate change and an increase in air pollution, including airborne desert dust.

TEXT **PETER HERGERSBERG**

Heat and drought: Faten, a Syrian farmer, sees these, too, as a contributing factor to the demonstrations that quickly escalated into a civil war in Syria. Speaking with the *New York Times* in 2013, she described what had happened in the years preceding the protests: she and her husband had cultivated grain and vegetables on their land, and thanks to the rainfall, had always had good harvests. “But then suddenly the drought came,” said Faten, who asked not to be quoted with her full name. “The country became a desert.”

Then she angrily explained about how the government ignored her pleas for aid. Her family, like countless other farmers, had no choice but to move to a city and seek work there. Some one million people left their homes during the drought. Particularly young men who had hopes of studying or getting married were hit hard by this. It was also the drought and the unemployment that consequently drove the people to revolution, she says: “When the first calls of ‘Allahu akbar’ then sounded, we all joined the revolution – immediately.”

“Climate factors are probably not the most important aspects in the Syrian conflict,” says Jos Lelieveld, Director at the Max Planck Institute for Chemistry in Mainz. “But the years of drought and the crop failures contributed to the resentment that led to the devastating civil war.” American climate researchers drew the same conclusion in the journal *PNAS* – with all due consideration given to the caution required when analyzing the causes of civil wars. The war in Syria, despite being based primarily on political, ethnic and religious issues, thus became a warning



A reason to go: Rising heat and more frequent sandstorms could force people in many regions of the Middle East and North Africa to leave their homes.

sign for the tragedy that climate change can bring particularly to countries in the Middle East and North Africa. When global warming destroys the foundation on which people build their lives, armed conflicts, migration and displacement are nearly inevitable.

The signs that this is how it will play out are multiplying. Heat records have regularly been broken in the Middle East in recent years. "This past summer, public sector employees in Iraq were sent home because it was just too hot to work," says Lelieveld. And that's just the beginning, as was made alarmingly

clear by a joint study he published in 2013 with researchers at The Cyprus Institute in Nicosia, where he also holds a professorship.

26 CLIMATE MODELS PRODUCED THE SAME FINDINGS

In this study, the researchers used a regional climate model for 18 cities in the eastern Mediterranean and the Middle East – from Athens to Riyadh – to calculate how the extreme temperatures will increase there. They recently substantiated and expanded these

projections to cover the entire Middle East and North African region. They simulated which temperatures can be expected there for the periods from 2046 to 2065 and from 2081 to 2100, in each case once for the summer months June, July and August, and once for the months December, January and February.

All 26 climate models the researchers used for their calculations – the predictions of which also form the basis for the report of the Intergovernmental Panel on Climate Change – produced the same findings: large parts of the



Left Jos Lelieveld hopes that his research will lay the scientific foundation for curbing climate change, or at least attenuating and adapting to its consequences.

Right The Middle East and North Africa are already seeing sandstorms and hot days, such as in Kuwait (top). If global greenhouse gas emissions continue to grow at the current rate, average temperatures in winter will rise by about 2 to 3 degrees Celsius (bottom left) and in summer by about 5 degrees Celsius (bottom right) by mid-century. In the dotted areas, the model calculations are in nearly complete agreement; the crosshatching indicates extensive agreement.

Middle East and North Africa can expect an extremely hot future. Accordingly, from Morocco to Iran and from Turkey to Saudi Arabia, as well as in southern Europe, climate change will have the strongest impact in the months June, July and August, when it is already very hot anyway. In that respect, this region differs from many other parts of the world, where global warming is most noticeable in winter.

According to the calculations, some regions will see an increase in average summer temperatures of about 4 degrees Celsius by mid-century – even if the average global temperature rise is limited to two degrees, in line with the goal set by the community of states at the most recent world climate summits. If humans continue to emit greenhouse gases at the current rate, then between 2081 and 2100, the average temperature will even be more than six degrees higher than at the turn of the last century.

What that means is hardly conveyed in the mere value of the average

temperature increase. Around the year 2000, the daytime temperature was already reaching 43 degrees, but mostly fell to below 30 degrees at night. These temperatures seem downright mild compared with what is yet to come: by mid-century, mean daytime temperatures will reach around 47 degrees and more on particularly hot days, and won't drop below 30 degrees at night.

200 UNUSUALLY HOT DAYS PER YEAR

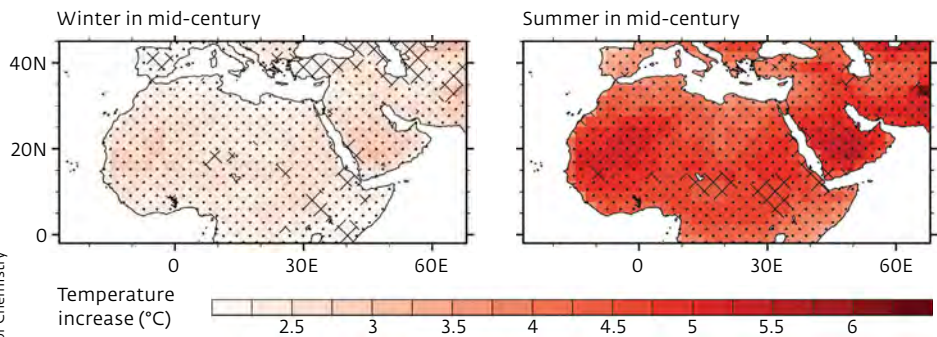
If humans manage to reduce carbon dioxide emissions in the second half of the century, the extreme temperatures will persist at about this level from 2050 on. However, if people continue to release greenhouse gases into the atmosphere unabated, then toward the end of the century we will see temperatures soaring as high as 50 degrees at midday, and still above 34 degrees at night.

Heatwaves will become more frequent. If humans don't curb their carbon dioxide emissions, we will see pe-

riods of extreme heat ten times more frequently than at the start of the 21st century, and they will last much longer. "The people in the Middle East and North Africa will then have to expect about 200 unusually hot days per year toward the end of the 21st century," explains Panos Hadjinicolaou, a climate researcher at The Cyprus Institute. And even if we emit fewer greenhouse gases worldwide from 2040 on, around mid-century, heatwaves will last the entire summer.

Between 1986 and 2005, people didn't have to endure extremely high temperatures for more than about two weeks at a time. However, meteorological data shows that the number of extremely hot days has already more than doubled in recent decades.

Of course, predictions always entail uncertainties. For the predictions the research team made for the Middle East and North Africa, however, the uncertainties are very minor. The researchers tested the reliability of the model calculations by also simulating tempera-



ture development for the Middle East and North Africa for the period from 1986 to 2005. The models reproduced it very accurately.

The development that extreme temperatures will force people to leave their homes also, of course, can't be predicted with absolute certainty. However, the point at which temperatures become unbearable isn't only a matter of personal perception; it is also one of physics: when temperature and humidity rise too severely, the human body can no longer maintain its normal tem-

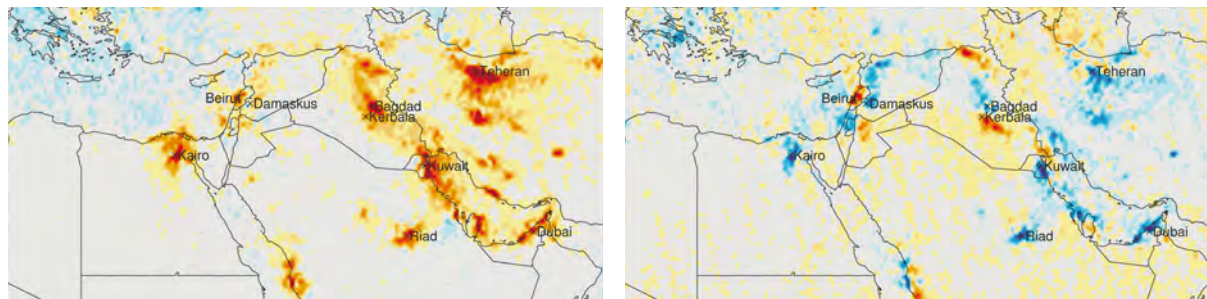
perature of 37 degrees solely through evaporative cooling by perspiration.

As two researchers at Loyola Marymount University in Los Angeles and MIT in Cambridge recently calculated, this will become more and more frequent in the Persian Gulf toward the end of the century. This is because humidity is high near the water, and in addition, according to the calculations of the two US researchers, daily maximum temperatures there will exceed 50 degrees Celsius in some areas. And this prediction isn't just for the distant fu-

ture: a record temperature of 54 degrees was already measured in Kuwait in summer 2016.

Jos Lelieveld is therefore certain: "Climate change will continue to significantly worsen living conditions in the Middle East and North Africa. Protracted heatwaves and sandstorms may make some areas uninhabitable, which will surely increase pressure to migrate."

As a result of increasing heat and drought, strong winds will raise more dust in the future, posing a growing life-threatening danger to people who get caught in a sand and dust storm. In addition, these storms are the most important reason why the concentrations of particulate matter in Saudi Arabia, Iraq and Syria have already risen sharply in recent years: 70 percent between 2000 and 2015. This was confirmed, based on satellite data, by a research team that included scientists from the Max Planck Institute in Mainz and, again, researchers from The Cyprus Institute, as well as from King Abdullah University in Saudi Ara-



Signs of crisis: While nitrogen dioxide emissions rose across nearly the entire Middle East from 2005 to 2010 (left), they fell in many regions between 2010 and 2014 (right). The colors indicate the changes in the concentration of nitrogen dioxide during the period under review – yellow and red signify an increase in the concentration, blue a decrease.

bia. Particulate matter is one of the nastiest air pollutants, because it causes respiratory and cardiovascular diseases and lung cancer.

Heat, drought and air that make breathing a health hazard will make the zone from the southern and eastern Mediterranean to the Gulf region a focal point of climate change. That worries Jos Lelieveld. “The aim of our research is to form the scientific basis for key decisions,” says the Max Planck Director. Only when scientists have thoroughly demonstrated and understood the changes can they provide the information that will allow policy and decision makers to curb climate change or at least attenuate and adapt to its consequences.

His additional position at The Cyprus Institute gives Jos Lelieveld a foothold in a region where global warming is a very hot issue. “Cyprus is part of the European Union, but it is much closer to the Middle East than it is to Europe,” he says. In the past several years, Lelieveld has repeatedly used the location to launch, together with his colleagues in Nicosia, studies on climate change and air pollution in the region. The researchers regularly cooperate with colleagues from other affected countries, such as Jordan, Egypt, Israel, Lebanon and Saudi Arabia. “This ensures that the knowledge and awareness of how severe the changes and their consequences are

will grow in these countries as well,” says Lelieveld.

FEWER NITROGEN OXIDES WHERE PEOPLE HAD TO FLEE

For instance, the staff at the Max Planck Institute in Mainz, together with a researcher from King Abdullah University, analyzed satellite data to investigate how nitrogen oxide concentrations developed in the Middle East between 2005 and 2014. According to their findings, nitrogen oxide emissions rose nearly everywhere in the region up through 2010, in parallel with economic growth.

After 2010, concentrations dropped in many areas, but that was seldom a good sign: it happened primarily in areas where armed conflicts and political crises stalled the economy and people had to flee. Conversely, nitrogen oxide pollution rose sharply in the areas where those who were displaced sought

refuge. “It is tragic that, to some extent, the negative nitrogen oxide emissions trends we observed, although good for air quality, relate to humanitarian disasters,” says Jos Lelieveld. Only in a few exceptional cases, such as in Israel and near the Persian Gulf, did stricter environmental laws lead to a reduction of nitrogen oxides in the air.

Jos Lelieveld hopes that his work will also help other governments develop environmental policies that will allow them to respond to the long-term threats posed by air pollution and climate change. He envisions a future in which the acute crises and conflicts have come to an end: “Of course there are, in some countries in this region, other problems that currently take higher priority.” Hopefully this will not remain the case for much longer – so that opportunities can be pursued to counter the scorching heat and poor air quality. ◀

TO THE POINT

- In the Middle East and North Africa, climate change is already causing longer hot periods and higher extreme temperatures. These effects will intensify in the coming decades.
- Climate change is also causing an increase in air pollution, especially fine particulate matter concentrations.
- Extreme heatwaves and increasing air pollution could compromise habitability in many regions of the Middle East and North Africa.

“Politics must invest in adaptation”

Walter Kälin is Professor Emeritus at the University of Bern Institute of Public Law. He is a dedicated human rights advocate with a particular focus on matters of migration and displacement. He served as Representative of the UN Secretary-General on the human rights of internally displaced persons and as envoy of the chairmanship of the Nansen Initiative for disaster-induced cross-border displacement. We spoke with him about the impact of climate change on migration and the possibilities for protecting people displaced across borders by the effects of climate change.

Professor Kälin, what role do changes in climate currently play as a cause of migration?

Walter Kälin: We know that, since 2008, some 22 million people have had to flee each year, at least temporarily, due to sudden weather events such as storms and floods. However, we don't know how many of those seek refuge abroad. We also don't know how many come to us due to gradual changes in climate, such as droughts and rising sea levels, because no one is going to mention drought as grounds for asylum, as prevailing law grants protection only to war refugees and victims of political persecution.

Should we expect a significant increase in climate refugees from North Africa and the Middle East in the coming decades because it is becoming too hot there?

I would first like to say that the term climate refugee is rarely used any more in the social and legal sciences.

Why?

These people aren't refugees in the legal sense because there is no element of persecution or danger due to human violence. In addition, many of those affected also reject the term. I recently participated in consultations on the Pacific island of Kiribati. There, a representative of an NGO told us very clearly: “We don't want to become refugees! Refugees are marginalized and must rely on humanitarian aid. Therefore, if we have to leave our islands, we want to be able to choose when and where we go.” Rather than climate refugees, we speak of disaster-displaced persons.

What exactly is the difference between the two terms?

The term disaster accounts for the human factor – a natural disaster is defined as an event that causes damage that exceeds what a nation or the population can cope with. Displacement in such situations is always multicausal and thus also dependent on human factors.

What does that mean for the question of whether climate change and extreme heatwaves in North Africa and the Middle East will lead to more migration there?

The number of disaster-displaced persons will certainly rise, especially if we do nothing, but exact forecasts are difficult.



Walter Kälin

This is because there are a wide variety of reasons for migration flows. Climate change itself doesn't directly lead to permanent migration. The main issue is how vulnerable people are to climate change and how well they can adapt to it. In the rich Gulf states, where life is already lived largely in air-conditioned spaces, people will be much more capable of adapting to heatwaves than a poor population in remote regions where heat and drought damage health and lead to agricultural problems. The more vulnerable people are, the more likely they are to go away.

So climate change will force poor people to migrate?

Here, too, we have to make a distinction. In order to leave, people have to have a



Lean years: Between 2007 and 2010, Syria suffered a drought that made farmers' lives extremely difficult. Some one million of them eventually gave up their businesses and moved to the cities.

certain amount of means that particularly the poorest of the poor lack. They will stay behind.

What can the countries in North Africa or the Middle East, for instance, and the international community, do to protect people against the consequences of climate change?

If people who are more vulnerable migrate sooner, this will give us the chance to intervene. We can reduce their vulnerability and improve their ability to adapt. I appeal to politics to invest in adaptation. There's a lot that can be done here.

What exactly?

There aren't yet any elaborate plans for skyrocketing temperatures, but it is conceivable to modify houses in such a way that they remain cool inside, and the abundance of solar energy in the affected regions could be used for cooling. The ag-

ricultural sector, too, could prepare for an increase in droughts by using modified irrigation methods and more drought-resistant plants.

But all of that is possible only to a certain degree.

That's undoubtedly correct, and that's why migration must be an adaptation measure. We need possibilities for legal migration. In the long run, rising sea levels will leave people from low-lying Pacific islands no choice but to permanently migrate or relocate. Australia, for instance, is already granting such people temporary work permits so their families can use the money they earn to better cope with the consequences of climate change. In other words, migration can also be circular ...

Which means?

Circular migration is when people migrate for a limited period of time to es-

cape the consequences of a natural disaster, such as a storm, flooding or drought. It can be for months or years. Appropriate programs need to be set up for this, and also for people who have to leave their homes permanently.

Does it make sense to establish similar global provisions for these people to those the Geneva Refugee Convention established for people who flee from armed conflicts?

I don't consider a global convention to be realistic. Also, it's difficult to find provisions that are simultaneously appropriate for the Pacific and North Africa. But 50 countries already have provisions for accepting people following major disasters in their vicinity. It is important to harmonize these provisions to allow action to be taken on a transregional level. They can be built on over time.

Interview: Peter Hergersberg

Wissen Sie, wie man „Berufungsliste“, „Blockseminar“ oder „Präsenzstudium“ ins Englische übersetzt? Oder welche Entsprechung der Ausdruck „die Anerkennung von Studien- und Prüfungsleistungen beantragen“ im Englischen findet? Dirk Siepmann | **Wörterbuch Hochschule | Forschung, Lehre und Management | Deutsch – Englisch | Englisch – Deutsch**



Gebundene Ausgabe, 2. unveränderte Auflage 2016, 476 S., 19,90 € (D) inkl. Porto, für DHV-Mitglieder zum Sonderpreis von 17,90 € inkl. Porto | **Zu bestellen über:** Deutscher Hochschulverband, Rheinallee 18-20, 53173 Bonn, Tel. 0228 9026666, Fax 0228 9026680 oder per Mail: dhv@hochschulverband.de

Dirk Siepmann ist Professor für Fachdidaktik des Englischen an der Universität Osnabrück. Er verfügt über eine jahrzehntelange Erfahrung in Fremdsprachendidaktik, Übersetzungswissenschaft und Lexikographie.

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An Ocean of Connectivity

Ships were long the fastest means of transportation, capable of carrying people and goods in large quantities. As a result, the seas became a medium through which a variety of nations made contact and carried out trade. To this day, ports serve as hubs and cultural melting pots. Taking the Indian Ocean as their example, **Burkhard Schnepel** and his team at the **Max Planck Institute for Social Anthropology** are studying how diverse networks developed across the waters.



TEXT **TINA HEIDBORN**

The Indian Ocean covers around 70 million square kilometers – approximately 15 percent of the Earth’s surface – providing a link, at its southern limits, between the Cape of Good Hope in Africa and Perth on Australia’s west coast all the way northward to Karachi, Pakistan and Kolkata, India. In between, the world’s third-largest ocean is dotted with islands and archipelagos. It’s not exactly a small area that Burkhard Schnepel chose to study. He is Professor of Social Anthropology at Martin Luther University of Halle-Wittenberg and a fellow at the Max Planck Institute for Social Anthropology, where he heads the “Connectivity in Motion: Port Cities of the Indian Ocean” working group.

Burkhard Schnepel’s primary interest in the Indian Ocean is what the water has made possible: “People have been travelling around this area for more than 3,000 years,” he explains. “It’s not just vast, it also has a long history.” For the social anthropologist and his project team, the Indian Ocean is a contact zone.

Thanks to the regular monsoon winds – blowing from the southwest in summer and from the northeast in winter – the Indian Ocean was relatively navigable during the age of sailing. Both historically and ethnologically, it can be regarded as a medium for contact and trade since ancient times, a “maritime silk road.” When Europeans arrived in increasing numbers from the 16th century onward, these opportunities for trade were a major factor: an ocean full of routes between Africa and Asia. Burkhard Schnepel has already done work on both continents. He wrote his doctoral thesis at the University of Oxford on the Shilluk people of South Sudan before turning his attention to field work and projects in eastern India. Now his focus has broadened to “Indian Ocean studies.” The ocean provides a framework, but to study the movements across it, researchers need to concentrate on individual points of departure and arrival and grasp the details: small islands and ports are a focal point of the project.

Burkhard Schnepel himself is dealing with an island that in the West is



Burkhard Schnepel (far right) is studying the island of Mauritius as a hub where knowledge derived from various cultures has been amassed, for instance about the effects of herbs (left). Immigrants have created their own traditions, such as the Sega style of music and dance (right). Today, Ebène Cybercity, south of the capital Port Louis, is an interface for high-speed optical fiber cables (right center).

regarded primarily as a vacation destination: Mauritius. To carry out field work and archival research, he has for years been making regular visits to the island nation, or more accurately to the main island of Mauritius and its capital and port city, Port Louis. Of decisive significance for him is its role as an important hub.

But what makes an island a hub? One key factor is the location: Mauritius was originally an uninhabited island, but one that was of great use to seafarers in the empty vastness of the Indian Ocean, on the route between East Africa in the west and India in the east. While the island is said to have been marked on the charts used by Arab sailors as far back as the 10th century, the first Europeans to “discover” Mauritius were the Portuguese in the early 16th century. Here they could take fresh food on board and refill their water casks, allow the crew a little relaxation, and repair and refit their ships.

It wasn’t until 130 years later that the Dutch established the first colonies. Approximately one hundred years later, the island was settled by the French, and later still, in 1810, it was conquered by the British. As time went on, Mauritius gained in importance as a trading

center: it was a way station for textiles and spices from India and ceramics from China, but also for slaves from Africa, of importance to the East India Companies of the European colonial powers. But the ships carried more than people and goods across the Indian Ocean. “They also brought ideas, languages, cultural and religious influences, and certain beliefs and expectations,” says Burkhard Schnepel.

SUGAR CANE WAS ONCE SMUGGLED ONTO THE ISLAND

And that’s another reason why Mauritius developed into a hub: over the past nearly 300 years, people from a wide variety of cultures have come to the island, creating an unusually varied pattern in a closely confined area. Social anthropologists and politicians alike refer to this as “unity in diversity.” To this day, a variety of religions and cultures exist more or less independently side by side. Languages and dialects from northern and southern India and China can be heard on the island along with – for official occasions – French and English, but the main language Mauritians use to communicate with one another is Morisyen, a unique Cre-

ole language that developed on the basis of French and other tongues that come together here. The multilingual character of the island remains one of its locational advantages.

Burkhard Schnepel believes that hubs are also distinguished by a high level of energy; they change the things that pass through their hands, transform them and add value. Schnepel mentions both historical and current examples: by the end of the 1960s, the island’s main export was sugar. Yet, originally, there was no sugar cane on Mauritius – it was smuggled onto the island from southern Asia. This was the only reason why Mauritius was able to start exporting sugar. What is more, the varieties with the highest yield were cultivated here, and were thus transformed before leaving the island again. Since it was granted independence in March 1968, the island has undergone an impressive economic transition. The traditional view that Mauritian society is defined by the centuries-old system of sugar cane plantations is not one that is shared by the social anthropologist from Halle. “Mauritius has come to regard itself as a hub and markets itself as such. Not just in maritime sectors, but progressively also in other areas too,” he adds.



Textile processing has since also become an important factor in the island's economic life: fabrics are imported from India and Bangladesh. It helps that two-thirds of Mauritians are of Indian origin. It also helps that the government has quite specifically created excellent conditions for the processing itself – an export trade zone that enjoys an extremely favorable tax status. The money to develop the textile factories comes predominantly from wealthy sugar barons, themselves French or of French origin – Franco-Mauritians make up around two percent of the population. There have also been investments from outside the island – once again across the sea. In the 1970s, many Hong Kong Chinese were seeking a safe haven for their money outside of the Crown colony that was facing integration into China in 1997. In Mauritius they were helped by the traditional links with Sino-Mauritians – inhabitants with Chinese roots who make up roughly three percent of the population. As a result, American and European manufacturers found excellent conditions here on the island, as well as the necessary expertise to have textiles fabricated here to a high standard. Imported materials

are now turned into luxury garments bearing prominent international brands – made exclusively for export to the West. The indigenous workers, in any case, are unable to afford the textiles and accessories they produce and finish. Often they are Indo-Mauritian and Creole women, the descendants of African slaves drawn from the poorest social strata.

Mauritius plays to its traditional strengths – excellent interconnections and communications stretching in many different directions – even in the rapidly changing age of digitization. “Back in 2000, the place where the new Ebène Cybercity now stands was still a sugar cane plantation,” Schnepel recalls. Today, some of the very fastest fiber optic cables lead to this small island in the Indian Ocean. The international communication technology segment has created around 12,000 jobs in the past few years, while developing the island's profile as an international financial services hub has added around 15,000 jobs since the early 1990s. It is primarily Indians who use the island's important banking sector for their transactions and their business with Africa. But for European and American firms, too, the island is

a good starting point for business in both principal directions across the ocean. “Sure there have been some shortcomings, but since its independence, Mauritius has been a democracy with a free press and political checks and balances,” Burkhard Schnepel explains. Mauritius has thus maintained its position as a stop-over anchorage and transshipment port for global business into the 21st century, and not only by sea.

PORT CITIES ARE THE PRODUCT OF NETWORKING

Head 5,500 kilometers northeast from Mauritius toward Southeast Asia and you are still sailing on the same vast ocean, but now in a different region in which, since fall 2014, Mareike Pampus has been engrossed. She is working on her doctorate under Burkhard Schnepel's guidance as part of the “Connectivity in Motion” research project. But is it actually possible to treat the vast area of the Indian Ocean as one unit and study it as such?

“Of course one might ask whether it wouldn't make more sense to consider the individual maritime regions separately, given the large number of dif-



ferent languages, cultures and states found around the Indian Ocean,” social anthropologist Burkhard Schnepel concedes. There are even scientists who, for this very reason, advise against speaking of the Indian Ocean as a single entity. However, if the links and interconnections are considered, if one’s research interest lies in the sea as a man-made contact zone, then one needs to take a view from sea to land. From the ocean to the different coastal and cultural areas where one might come ashore. As part of his research in this “maritime” dimension, Schnepel is also interested in acquiring a new perspective on the adjacent lands.

FIVE NUTMEGS WERE WORTH A WHOLE HOUSE

Mareike Pampus has found her personal niche: her work focuses on the port city of George Town on the island of Penang, now part of the state of Malaysia. “Port cities are important in our project because they often originated through networking and interchange,” she says. “What is new about our research is that we view them less as a starting point for connectivity – which they are – than as the result of networking.”

The British regarded the Indian Ocean as *mare liberum*, a free sea, which offers access to all and should specifically not be subdivided into the demarcated ownership of the bordering states. In order to position themselves firmly in the competitive economic environment engendered by this openness, they secured some strategically important trading centers in the eastern Indian Ocean. In the late 18th century, for instance, the British East India Company in the person of merchant and seafarer Francis Light settled at the northeastern tip of the island of Penang. He named the place George Town, though at first it was less a town than a free port with an adjoining settlement, its function being to participate in the extremely lucrative trade in spices. “Five nutmegs would buy a house in London in those days,” says Mareike Pampus.

The island of Penang lies at the northern end of the Straits of Malacca, then as now one of the world’s most heavily traveled waterways. In ancient times, this was the maritime route between China, India and the west-Asian world. The first Europeans to arrive here in the 16th century were the Portuguese, followed by the Dutch, French

and British, all seeking to enter into this well-developed web of connectivity and extend the routes for the transport and distribution of Southeast and East Asia’s costly produce further westward. To the already existing network they added their own new points of contact – such as George Town.

Others followed: “The pattern set by George Town can be traced as far as Singapore and even to the coast of Australia,” says doctoral student Mareike Pampus. A few decades later, at the start of the 19th century, and around 600 kilometers from George Town, another employee of the British East India Company established an important port city: Singapore. Its founder, Thomas Stamford Raffles, had previously been Governor General of George Town. History draws a similar line from George Town to Australia, where William Light, son of George Town’s founder Francis Light, who had spent the first six years of his life in George Town, went on to found another Indian Ocean port named Adelaide. “This shows,” says Mareike Pampus, “how the concept of a city can cross the sea.”

Of course the British weren’t alone: besides the colonial rulers, it was predominantly the Chinese who settled in

George Town on the Malaysian island of Penang is a melting pot of religions: Situated within a few hundred meters of one another on a road called the “Street of Harmony” are a mosque, a Hindu temple and a Christian church (left, from left). In addition, a statue of Guanyin, the goddess of mercy revered by Taoists and Buddhists, is also occasionally erected to collect donations (right).



George Town; to this day, some 80 percent of the city’s inhabitants are of Chinese origin. Most of them, however, did not come directly from China. They had previously lived in the nearby trading center of Malacca, or in Indonesia, much like the Indian incomers. Like so many other places of contact in the Indian Ocean, George Town, too, is a diverse mix of languages, cultures and religions. Here, too, we find unity in diversity, preserved to this day in the language and in specific terminology. For example, among the inhabitants of George Town are the “Jawi Per-a-nakan” whose forefathers were a mix of southern Indians and Malays. The name includes the word for “child” (anak). A pattern of marriage that can be traced over centuries may be described ethnologically as one of local women bearing children by husbands who arrive as traders from foreign regions.

CULTURAL DIVERSITY ON UNESCO WORLD HERITAGE LIST

The “Baba-Nyonya,” commonly described in English as “Straits Chinese,” are a special case in George Town. This particular group dates back to the restructuring of the British colonial ad-

ministration, when, in 1826, the British amalgamated their three colonial possessions along the Straits of Malacca – George Town, Malacca and Singapore – to form the Straits Settlements. Chinese who were born in these Straits Settlements and identified strongly with this origin often received a British education and were taught British social standards. As such, they were predestined as traders to cooperate particularly successfully with the English merchants of the East India Company. “Even if their appearance was Chinese, they were highly westernized in character,” Mareike Pampus continues. The Baba-Nyonya remain to this day a separate group within the population of George Town, with their own cultural identity and Creole language.

Who am I? Who were my forefathers, where did they come from and how did they get here? How do I see myself and my cultural imprint? It is these and similar questions that Mareike Pampus seeks to answer on her research visits to George Town, where she is now staying for a second six-month term. She attempts to enter into discussion with the local inhabitants, conducts long interviews,

sometimes several times with the same individuals. It is less a matter of questioning than of allowing them to tell their individual stories. Her goal is to acquire a more accurate view of this very specific situation, of the inhabitants of a port city in the Indian Ocean with their cultural and historic heritage.

There has been a considerable boost in acknowledgment of the manifold roots and cross-cutting connections across the Indian Ocean in recent years. George Town and Malacca were both included in the UNESCO World Cultural Heritage list in 2008 as bearing outstanding witness to the trade and cultural interconnections that have developed over more than 500 years along the Straits and across the wider Indian Ocean. As grounds for its decision, UNESCO cited the varied influences deriving from Asia and Europe that have contributed to a unique multicultural heritage in these cities. Guide books to George Town describe Buddhist temples side by side with Hindu shrines, churches and mosques.

On a research visit to Mauritius in the spring, Burkhard Schnepel focused on the island’s typical style of music



For her doctorate, Mareike Pampus (large photo, left) is conducting interviews with inhabitants of varying origins in George Town, Malaysia, in order to study their cultural imprint. One important group is the “Baba-Nyonya,” descendants of Chinese immigrants who preserve their own traditions (small photo).

and dance: the Sega. Tour operators are fond of advertising it as an illustration of the cheerful approach to life on Mauritius. It was originally brought to the island by African slaves who labored in the sugar cane plantations in the 18th century. Once sung and danced in secret by mainly Creole Mauritians, today all of the islanders – including Franco-, Sino- and Indo-Mauritians – collectively identify with it. More than twenty different forms have developed and are the subject of Burkhard Schnepel’s social anthropological studies: both modern and traditional variants that are even taught at school, amalgams such as Seggae (part Sega, part reggae), but also the so-called Sega tipik or Sega typique. This more traditional Sega

was recently declared by UNESCO to be part of the intangible World Cultural Heritage – a tradition that has resulted from the interchange and coexistence between peoples coming to Mauritius from different parts of the Indian Ocean and beyond.

Even though the world’s third-largest ocean lies primarily in the southern hemisphere, far removed from Germany, Burkhard Schnepel has the impression that awareness of this region is growing here, too. German politicians, at least, are showing an increasing interest. “For Germany and

for Europe, it is high time to take a closer look at the Indian Ocean region,” said German Federal Foreign Minister Frank-Walter Steinmeier at a conference he organized in Berlin in June 2015. The theme of the conference was “The Indian Ocean – A Maritime Region on the Rise.” In other words, it’s a good time for social anthropologist Burkhard Schnepel and his team at the Max Planck Institute in Halle to take a closer look at this rising region and firmly anchor their Indian Ocean studies research field in the German science landscape. ◀

TO THE POINT

- If one considers the Indian Ocean as a unit, it is possible to identify hubs: places that serve as nodes connecting the ocean’s different littoral states and their cultures.
- The defining features of a hub are its location – such as at the intersection of important shipping routes – a wide variety of languages and cultures, and the fact that goods are transformed and value added prior to onward shipment.
- Among the examples studied by the scientists in Halle are the island of Mauritius and the Malaysian port city of George Town.

Photos: Mareike Pampus (2)

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Coal – in Liquid Form

In 1925, **Franz Fischer** and **Hans Tropsch** at the **Kaiser Wilhelm Institute for Coal Research** in Mülheim an der Ruhr discovered how to turn coal into gasoline. Today, Fischer-Tropsch synthesis is experiencing a renaissance, as it is used to refine far more than just coal. The process can also be applied to turn natural gas, biomass and even household trash into fuel.

TEXT **ELKE MAIER**

Dwindling oil deposits are forcing scientists to be inventive. Chemists are now able to transform a wide variety of carbonaceous raw materials into high-quality liquid fuels. Some airlines are even experimenting with kerosene from household trash. The method used to bring about this transformation is neither alchemy nor is it new. It was developed more than 90 years ago at the Kaiser Wilhelm Institute for Coal Research in Mülheim an der Ruhr.

The Institute in Mülheim opened its doors for the first time on July 27, 1914. Its declared aim was to “increase the intrinsic value of coal.” The first Director was Franz Fischer – a man considered to be an “inventive mind” and a “very skillful experimenter.” Fischer had studied chemistry and completed his doctorate at the age of 22, after just four semesters. When he accepted the position in Mülheim, he was 36 years old and his research career had already been meteoric.

Initially, the Institute’s primary task was to support the German war economy by producing fuels for automobiles, tanks and airplanes. Oil was in scarce supply, but coal was plentiful. The only problem was that it had to be liquefied. Chemically, this required the following steps: First, the bonds between the hydrocarbon molecules that give the coal its stability had to be broken open. After that, the hydrocarbon chains of the liquid fuel had to be assembled.

A year earlier, in 1913, German chemist Friedrich Bergius had already found a way to do this – he even earned the Nobel Prize for it in 1931. But the Bergius process has some serious disadvantages: For one thing, it can be used to liquefy only geologically young types of coal, such as lignites, but not geologically older, hard coals that have a higher energy content. And for another, the method works only under enormous pressure, which creates technical problems.

What Franz Fischer thus had in mind was a “synthesis of oils from gases.” It all sounded quite simple in theory: The first step of his two-step process would be to heat coal dust with steam and



Putting coal into the fuel tank: Franz Fischer (left) and Hans Tropsch.

oxygen to crack all the carbon bonds and generate a mixture of carbon monoxide and hydrogen – the so-called synthesis gas. The second step was to then channel this gas over a catalyst on whose surface the molecules would link up to form complex hydrocarbons.

But as is so often the case, here, too, the devil lay in the detail – or more precisely: in the catalyst. Its task was to stimulate the otherwise far too sluggish reaction process, and also to ensure that the desired end products were created. The hunt for a suitable material resembled the

proverbial search for a needle in a haystack.

In the early 1920s, the experiments on gas synthesis were expanded. One of the scientists involved was Hans Tropsch who, according to a colleague, was an “outstandingly competent” chemist and a “master at using a slide rule for difficult calculations.” He had been recruited by Franz Fischer and entrusted with heading the “gas catalysis” department.

The scientists conducted countless screening experiments in special high-pressure devices. They tinkered with several settings at the same time, varying not only the catalyst but also the temperature and pressure, as everything taken together determined the outcome of the reaction.

It was months before the first glimmer of hope appeared. The researchers found that the apparatus held reaction mixtures that contained alcohols, aldehydes and ketones, among other things. To keep things simple, the chemists called the mixture “synthol.” The catalysts they used were iron filings that the researchers had impregnated with potassium hydroxide or rubidium hydroxide.

One member of the Institute, Carl Zerbe, did some initial road tests on a 1922 4HP NSU motorbike powered by the engine fuel they had laboriously obtained in minute amounts. “But synthol still wasn’t a high-quality fuel,” explains Matthias Haenel, professor emeritus at the Institute in Mülheim. “It still contained a lot of oxygenated compounds that cause the engine to corrode.”

So the search continued – and sorely tested the patience of the researchers. Some catalysts became inactive after only a very short time; others produced only water as their end product. The chemists had to use hammers and chisels to remove some of the catalyst charges from the pipes again, as so much carbon deposited in them.

At the beginning of 1925, a turning point finally appeared to be on the horizon. A journal containing an article by a certain Georges Patart arrived in Mülheim. In this article, their famous French colleague described how methanol – a simple compound with one carbon atom – could be synthesized with the aid of a zinc oxide catalyst. The researchers in Mülheim immediately began their attempts to cook up the experimental recipe – and succeeded on their first try. They were amazed at the “smooth, homogeneous formation of methanol on the almost unchanged white zinc oxide.”

From then on, they stuck to the catalyst described by Patart. Was it also possible to make long chain hydrocarbons in this way?

GEO, Issue 3/1983



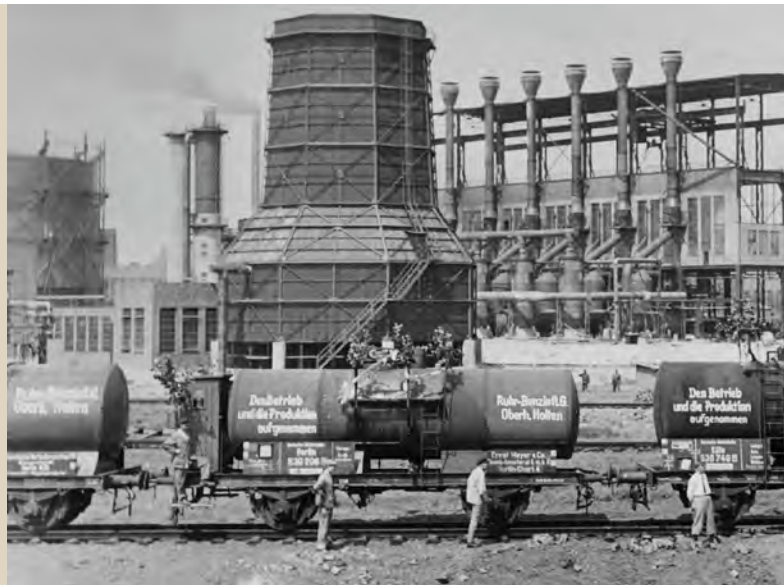
From about 2020 on – so in just 40 years – coal will play the leading role, and oil will only have a bit part.

The researchers experimented with zinc oxide, adding other chemicals they thought would be suitable. On May 25, 1925, their hunch proved to be correct: this was the day on which they first succeeded in synthesizing higher hydrocarbons at normal pressure. The philosopher’s stone turned out to be a mixture of iron and zinc oxides. It was later found that iron and cobalt catalysts are even better. On July 20, 1925, Franz Fischer and Hans Tropsch applied for a patent for their method.

The first industrial plant to operate using the process discovered in Mülheim went into operation in the mid-1930s in Oberhausen. In the early 1940s, nine German production sites were producing around 600,000 tons of liquid hydrocarbons every year. Nor were the primary products of Fischer-Tropsch synthesis used only for fuel production: they could be processed further into lubricating greases, soap or detergents, for example. It was even possible to conjure up synthetic butter.

The inventor of this synthetic edible fat was chemist Arthur Imhausen. In the Second World War, Germans fighting in the African campaign and on U-boats ate almost exclusively Imhausen’s fat. It was easy to digest, didn’t go rancid and is reported to have had quite a nice taste. Experts confirmed that the daily consumption of up to 100 grams “is harmless and causes no irritations or disorders whatsoever.” His creation was thus given the go-ahead as the first synthetic food for human consumption.

After the war, however, the Fischer-Tropsch products, and thus synthetic butter as well, were soon off the table again. The synthet-



Triumphant progress of synthetic gasoline: Wagons loaded with Fischer-Tropsch fuels wait in front of Ruhrchemie AG in Oberhausen-Holten before they set off.

ic fuels made from coal couldn’t keep up with their oil-based counterparts. The plants were dismantled. It wasn’t until the oil crisis in the 1970s that the process enjoyed a brief revival in Germany.

Franz Fischer and Hans Tropsch didn’t live to see the checkered future of their invention. Fischer retired and moved to Munich, where he twice lost all his possessions in air raids. He suffered from malnutrition and died at the age of 70 in the hunger winter of 1947. Tropsch moved from Mülheim first to Prague and later to Chicago. In 1935, illness forced him to return to Germany, where he died a short time later at the age of just 45.

After the war, the process developed by the two chemists first made waves in South Africa. The country’s policy of apartheid meant that it was subject to sanctions, and oil shipments were banned. What they had, however, were masses of coal. The government thus turned to the Fischer-Tropsch method and founded a company in 1950 that now trades under the name of South African Synthetic Oil Limited (Sasol). The company still supplies around a third of the fuel sold in the Cape, and now it processes natural gas as well as coal.

The method is now enjoying a comeback in other countries, too. “Its big advantage is that basically any carbonaceous raw material can be used in the process, so also natural gas, biomass and even household trash,” says Ferdi Schüth, Director at the Max-Planck-Institut für Kohlenforschung. “The method also delivers very pure, sulfur-free fuels.”

This fact has been exploited in Qatar, for example, where Shell commissioned Pearl GTL, the world’s largest gas-to-liquids (GTL) plant, at the end of 2011. It transforms low-priced natural gas into high-quality liquid fuel. Annual production totals around 5.6 million tons – more than nine times the amount produced in the early 1940s in all of Germany. The synthetic diesel from the desert is also available at German gas stations.

In Germany, however, it won’t be worth constructing Fischer-Tropsch plants again until the price of oil rises: “A barrel currently costs around 40 dollars, so it isn’t worth producing it with this method,” says Schüth. Yet, although it has always been possible to find new sources of oil, the day will come when oil reserves are exhausted. Then reviving the Mülheim method may be an option in Germany, as well. Whether Imhausen’s spread will also enjoy a revival, however, is questionable.

On Course for Careers

“Sign Up!” program for outstanding female postdocs moves on to the fourth round



Working together for a career in science – the participants in the fourth round of “Sign Up!”

Women are underrepresented in science, particularly in management positions. The MPG intends to change this. One of the measures it has put in place is a training program designed explicitly for female postdocs. Over 70 female researchers have already taken part – and both evaluation and feedback from participants show that the course is a winner.

The English expression “to say it in a nutshell” aptly describes the program taking place in this seminar room in Berlin’s Kreuzberg neighborhood: a science slam in which participants have just three minutes to present their work; so little time that complex research topics must almost literally fit into a nutshell. What’s more, when 19 female postdocs from the MPIs meet for a career training session, the language spoken is English. To start with, the mint-green upholstered chairs were arranged in a circle, then in rows so that each speaker faces a seated audience. One might think: 1 against 18, but in fact they are all supportive of one another.

Each presentation is followed by applause. And constructive feedback.

Self-presentation training is just part of a package designed to provide the participants with some important knowledge, fundamental strategies and practical tips that will help them launch their careers in science. Becoming a postdoc is in itself an ambitious achievement, but for a professorship, the hurdles are far higher.

And some of these hurdles are still gender-specific, and thus lend themselves to discussion among an all-female group of scientists, as “Sign Up!” project head Katharina Schiederig made clear in her presentation as part of the first course module in June. “The desire to start a family and the role of a mother are significant in themselves. But more general aspects, such as the Academic Fixed-Term Contract Act, are just as important,” says Schiederig.

As a qualified diversity trainer with a doctorate in political science, she works for the think-tank EAF Berlin, a not-for-profit organization that pro-

motes equal opportunity through training in politics, business and science. “Sign Up!” was developed jointly with the MPG and has been running since 2009. It is aimed explicitly at women working as postdocs. Particularly the years after a doctorate, during which one normally conducts research in a department with an institute Director, sets up initial projects of one’s own, or supervises doctoral students, are a kind of crossroads to the future.

“It’s life’s rush hour, when there are so many decisions to be made: Do I go into industry or stick with research, do I start a family – and how do I bring it all together? All of these questions must be answered,” Schiederig continues. This is where “Sign Up!” comes in, to enable young women to make a balanced choice from among the broadest possible range of options. “The most important part of the course is that each participant develops her own plan for what she wants to achieve – using the tools acquired in the seminar.”

This self-analysis, which begins in the first module and continues at subsequent meetings through follow-up discussions in small teams, is something that Elisabeth Wenger also finds very important. “It helps enormously to look closely at how career paths in science unfold and which success factors are really relevant. To then discuss one’s own status quo and one’s own goals was certainly not easy, but very valuable,” says the postdoc from the MPI for Human Development in Berlin.

After all, the process also makes clear where there is room for improvement. For example, when it comes to updating one’s CV, not just with a list of publications, but with details of teaching experience, external funding, cooperative projects and time spent supervising students. Isabella Guido, a postdoc at the MPI for Dynamics and Self-Organization in Göttingen, puts it thus: “We are scientists, we spend our days in the lab because research fascinates us. And it’s easy to believe that that will simply turn into a career. But the exact opposite is true. ‘Sign Up!’ opens your eyes and is a real-

ly wonderful opportunity. And the course also brings us into contact with other women who share the same goals.”

One of the selection criteria is that participants actually intend to continue working in research. Another is that they excel in their own field, which is why they must be nominated by a Max Planck Director, as Martha Roßmayer explains. She is the officer in charge of “Sign Up!” at Administrative Headquarters.

Since the program launched in 2009, there have been three courses; the fourth began in June and runs until January. “‘Sign Up!’ has received highly positive evaluations, which is why it continues, even though the MPG otherwise tends to avoid gender-specific formats for advancement. But in this case, the need is evident and the demand is great,” says Roßmayer. Consideration is currently being given to the possibility of allocating more money and offering career courses annually in the future. Independently of this program, Administrative Headquarters also maintains a list of advanced train-

ing courses that are also open to men – bookable via the respective institute.

The second module taking place in the seminar room in Berlin also includes leadership training, since the women will have management duties to perform in the next stage in their careers, as Research Group Leaders. Also important are the discussions with female Directors and science managers who describe their ascent to the top. These will be repeated in the third and last module, but by then the emphasis will be on insight into the appointment procedure and how best to prepare for it.

One item that is not on the official program agenda is networking. This simply develops – coordinated, of course, by an alumnae network of all previous participants – as the course proceeds, which could already be sensed during the science slam in the seminar room in Berlin. The second module begins with each participant recounting what she was thinking about on her way to the course. Several commented, as they sat in a circle, that “it’s great to see everyone again.”

Always on the Ball ...



Early in September, chemists, physicists, pharmacists and engineers from 22 countries spent three days at the MPI for Dynamics of Complex Technical Systems in Magdeburg discussing trends in the development of industrial crystallization processes. Afterwards, true to the tradition of the conference – now in its 20th year – the international exchange continued on the soccer field. Nearly 40 of the 100 or so conference participants joined in, and thanks to the multitude of nationalities, almost every continent was represented. This small-scale World Cup was played out between four teams in two semi-finals and one final. The winner was eventually decided by a penalty shoot-out. Our photo shows Erik Temmel from the MPI in Magdeburg in action: he’s parrying a header from Hideyuki Nagao, a conference participant from Tokyo.

Setting the Course for 2017

PhDnet representatives hold their annual meeting in Berlin



Max Planck Vice President Angela D. Friederici answered questions on equal opportunity. PhDnet Spokesperson Martin Grund was delighted with the lively exchange.

A year ago, as Martin Grund well remembers, PhDnet adopted an amendment to its bylaws that provided for a doctoral student representative to be elected at every Max Planck Institute. Now, after “months of hard work,” says the departing PhDnet spokesperson, the network can harvest the fruits of its labors: “The 2016 General Meeting was

attended by elected representatives from 66 institutes, which is 80 percent of the total. So the amendment is well implemented.” This worked because support is strong among doctoral students, because an online tool was employed for the elections, and because “the administrations of the institutes were very supportive of us.”

The General Meeting, for which the doctoral student representatives from the individual MPIs and other PhDnet supporters converged on Berlin in early November, was once again attended by several invited guests, among them Vice President Angela D. Friederici. She provided the junior scientists with a look at the work of her Presidential Committee on Equal Opportunity. “The debate that followed was both open and lively. Three PhDnet representatives were even invited to the Committee’s next meeting,” says Grund. They will be there to put forward the points developed by the PhDnet working group that was specifically set up to look into this issue.

Also at the General Meeting, which was held at the MPI for Infection Biology in Berlin, the new PhDnet Steering Group was elected. Starting in 2017, Jana Lasser, MPI for Dynamics and Self-Organization, will represent the doctoral students of the CPT Section; Lisa Scheuermann, MPI for Infection Biology, will represent those of the BM Section; and Teresa Hollerbach, MPI for the History of Science, those of the HS Section. In addition to the Chair-/Spokesperson Leonard Borchert, MPI for Meteorology, the leadership team also includes Secretary General Rafael Laso Pérez, MPI for Marine Microbiology, and Treasurer Gabriel Guerrero, MPI for Biology of Ageing.

Ripples in Space Reach Harnack House

News of the discovery of gravitational waves in September 2015 spread around the world, with the US LIGO detector in the spotlight. In mid-October, Rainer Weiss, one of the senior scientists working on this project, delivered the Harnack Lecture before an audience of 160 in Berlin.

For the physicist, it was a homecoming. Born in Berlin in 1932, his family was forced to flee a few years later, first to Prague, then to the US. Weiss studied physics at the Massachusetts Institute of Technology (MIT), where he obtained his doctorate in 1962 and has been a professor since 1965. Over the years since, his work has spanned various fields.

Since the 1980s, Weiss has been studying gravitational waves. He enhanced the laser interferometer – at that time, this was a new technique, and a group from the MPI for Physics and Astrophysics became the first in the world to use it in their research.

This pioneering work created the basis for the large detectors, including LIGO. In his Harnack Lecture – which prominent scientists have been invited to deliver each year since the MPG conference venue was reopened – Weiss presented a retrospective on gravitational wave research and reported on this particular facility, which encompasses two observatories in Hanford and Livingston. Gravitational waves were first detected there on September 14, 2015.

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- Associated research organizations

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MAX-PLANCK-GESellschaft

Publisher's Information

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

Publisher's mailing address

Hofgartenstraße 8, D-80539 Munich
Tel. +49 89 2108-1719 / -1276 (Fax: -1405)
e-mail: mpf@gv.mpg.de
The magazine as ePaper: www.mpg.de/mpresearch
App for free download: www.mpg.de/mpr-mobile

Content Authority

Dr. Christina Beck (-1276)

Editors-in-Chief

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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

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

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