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Max Planck RESEARCH

The Science Magazine of the Max Planck Society 4.2009

FOCUS

Strange Worlds

Excursions through the Solar System

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It Takes a Single Gene to Make Stem Cells

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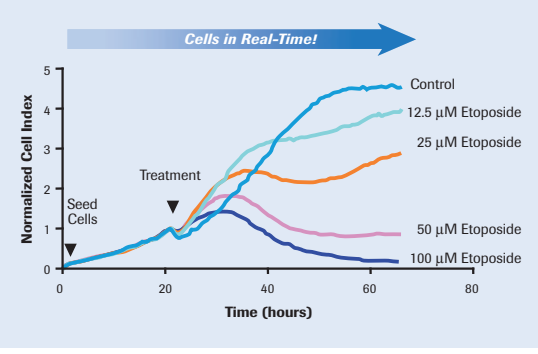

Figure 1: Real-time monitoring of cytotoxicity through DNA damage. Etoposide is a DNA damaging agent which induces apoptosis in high concentrations, while at lower concentrations it leads to S-Phase and/or G2 arrest.

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Dear Readers,

The view of the stars, the movements of the planets through the constellations, even the ability to determine days of special importance through the position of the Sun and the stars above the horizon: all of these phenomena are closely connected with the cultural history of mankind and have been the subject of speculation and scientific inquiry for millennia. Today, we know that our solar system is part of the Milky Way, one of the billions of galaxies that make up the universe. Seen against the vastness of space, our home seems very small. Our Sun, as the central star in the solar system, is orbited by planets that, in turn, have their own satellite moons. There are also planetoids and comets – the latter look like visitors from foreign worlds. It is only in recent years that we have learned where they come from and what they are made of. Collisions with such cosmic rocks have helped shape the fate of the Earth and left their mark on its surface.

When the Earth's orbit intersects with clusters of meteoroids, they are visible on clear summer nights as shooting stars. We interpret their glow as a harbinger of good fortune, but if the Earth were to be struck by a large asteroid or comet, the consequences would be fatal. Such a scenario has been the subject of more than one Hollywood horror film.

So it comes as no surprise that science is asking a few questions: What kind of structure, internal composition and stability do these heavenly bodies possess? Can modern satellite and rocket technology enable us to approach them and possibly land on them? We would very much like to take samples and analyze their composition, for their origins date back to the time when our solar system was created out of cosmic dust. What might such analysis tell us about the origin of the Earth and its siblings? Why does the Earth differ so dramatically from Venus and Mars? Why is there water on Earth and an atmosphere that has allowed life to begin and to evolve? Is the Earth alone in supporting life in our solar system, and if so, under what circumstances did it originate?

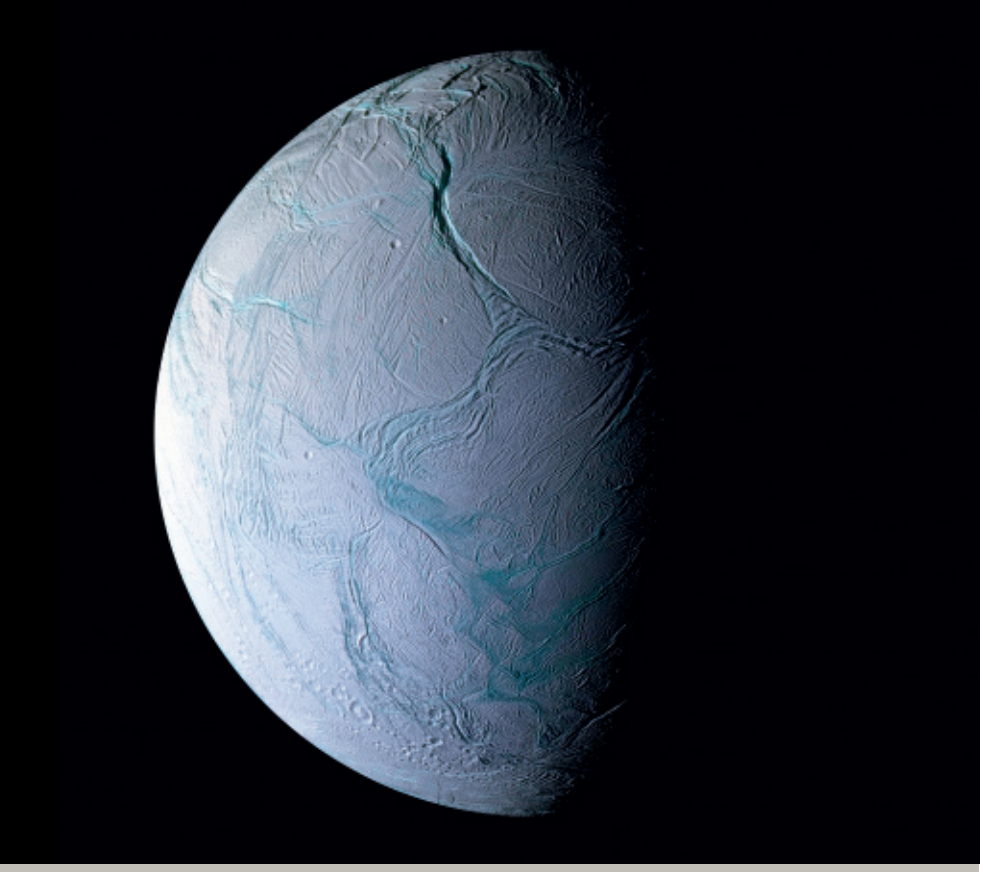
Questions like these have long been asked and answered with speculation. And so it is the desire for concrete data and facts that justifies the high cost of revealing the true nature of our solar system beyond all speculation. Missions to other planets and their moons can be financed only through international cooperation; the costs are far beyond the means of national research organizations.

For decades, the Max Planck Society has accepted a commitment to act as the German partner in such multinational projects. The Society's institutes also coordinate the roles played by German universities in major interplanetary missions. This issue of MaxPlanckResearch offers you insight into some exciting projects, including the search for water on Mars and Saturn's moon Enceladus, the exploration of Venus's stormy atmosphere, and investigations of planetoids and comets.

Interplanetary missions are protracted affairs. Designing and building the instruments can take up to ten years. The journey to the target destination can often take many years more. Then it is a question of collecting and analyzing the data. The successful completion of a mission requires a stable organization, oriented toward long-term objectives – the kind of organization the Max Planck Society guarantees in Germany. That is why the Society is valued as a reliable partner in the international competition to participate in exploring the solar system. The public interest in the results of such missions justifies the necessary efforts and resources.

Gerhard Wegner
Emeritus Director at the Max Planck Institute
for Polymer Research

Photo: MPI for Polymer Research – C. Costard



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Cover photo: NASA/JPL-Caltech/University of Arizona
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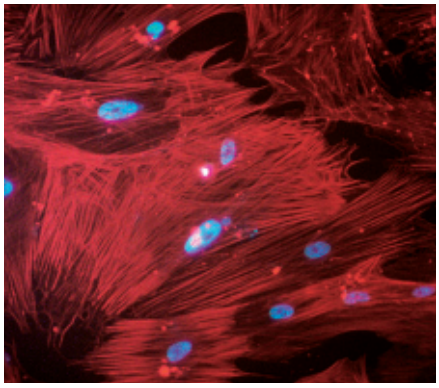

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Photos: MPI for Molecular Biomedicine – Kinarm Ko; Frank Vinken; Sven Döring (from left to right)

Clouds – A Silver Lining for Climate Researchers

What happens inside clouds? How do they change under varying environmental conditions? Clouds remain a source of uncertainty in model-based forecasts for our future climate. Now researchers at the Max Planck Institute for Meteorology are seeking to change that – in the coming months, they will be launching a two-year empirical field study on the Caribbean island of Barbados. The scientists will concentrate on the interaction between aerosols, clouds, precipitation and climate. How is the distribution and structure of clouds controlled where the trade winds blow, and how do they react to changing environmental conditions? These are the central issues this project will address.

In close cooperation with the Caribbean Institute for Meteorology and Hydrology, the Max Planck researchers will be installing the latest remote sensing instruments – such as LIDAR and cloud radar – on the windward side of the island's bluff. They will also analyze satellite data and measurements taken by the research aircraft *HALO*.

Conditions on Barbados are ideal for the measurements. The island lies in the eastern approaches to the Caribbean and there are no other land masses to disturb the trade wind flow. The flow patterns and cloud formations also vary widely on Barbados, depending on the season. In winter and early spring, the trade winds dominate, with occasional human interference through the burning of biomass. In early summer, mineral dust is carried all the way from the Sahara, while bursts of deep tropical convection become the defining feature as the season draws to a close. The location is also attractive for the unique long-term series of measurements of dust and aerosol concentrations conducted by scientists from the University of Miami.

Science in paradise: Researchers intend to carry out a field study of the effect of clouds on climate on the Caribbean island of Barbados.

Photo: MPI for Meteorology

The field study offers the opportunity to collect large quantities of ground measurement data that serves to support research into the relationships between cloud cover and precipitation, as well as ambient meteorological conditions such as moisture and aerosol composition and concentration. The resulting database will also allow the results of previous field studies to be generalized and substantially improve the interpretation of data from the new sensor generation aboard remote sensing satellites. The capabilities of the new German research aircraft *HALO* also offer the opportunity to combine local measurements with the overall structure of the trade winds.

Astrocenter in China

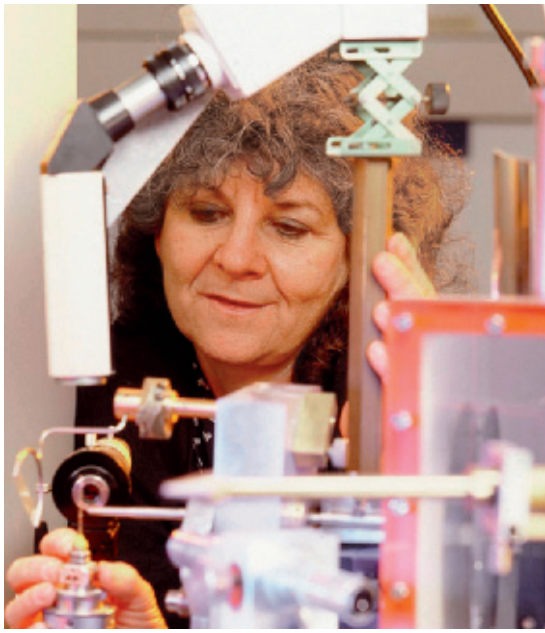
The long and successful cooperation between Max Planck astronomers and their colleagues at the Chinese Academy of Sciences is taking on a new dimension: A Max Planck China Center for Cosmology and Astrophysics is being set up at the renowned University of Science & Technology in Hefei, and will also be closely linked to a graduate school. Scientists there will be studying the origin and development of galaxies, supermassive black holes, gamma bursts, dark matter and dark energy. They will use both computer simulations and statistical methods to analyze the data from their observations. Max Planck scientists will also teach at the Graduate School as guest lecturers. This new instrument of international cooperation is an inter-institutional initiative headed by the Max Planck Institute for Astrophysics; other MPIs taking part in the project include the Institutes for Astronomy, Radioastronomy and Extraterrestrial Physics. The new Center will begin official operation in January 2010.

Nobel Prize in Chemistry for Ada E. Yonath

"I am delighted that Dr. Yonath's award honors a scientist who was associated with the Max Planck Society for more than 20 years. It was during this time that the key foundations were laid for the research for which she has now been awarded the Nobel Prize," said President Peter Gruss on learning of the distinction for Ada E. Yonath.

The researcher worked from 1979 until 1984 under the leadership of Heinz-Günter Wittmann in the department of ribosomes and protein biosynthesis at the Max Planck Institute for Molecular Genetics in Berlin. During this period, she began her study of the structure and function of ribosomes. From 1986 to 2004, she headed the Max Planck ribosome structure research group at DESY (the German Electron Synchrotron) in Hamburg. Ada E. Yonath now works at the Weizmann Institute of Science in Rehoboth, Israel. She shares the Nobel Prize with Venkatraman Ramakrishnan (MRC Laboratory of Molecular Biology, Cambridge, England) and Thomas A. Steitz (Yale University, USA).

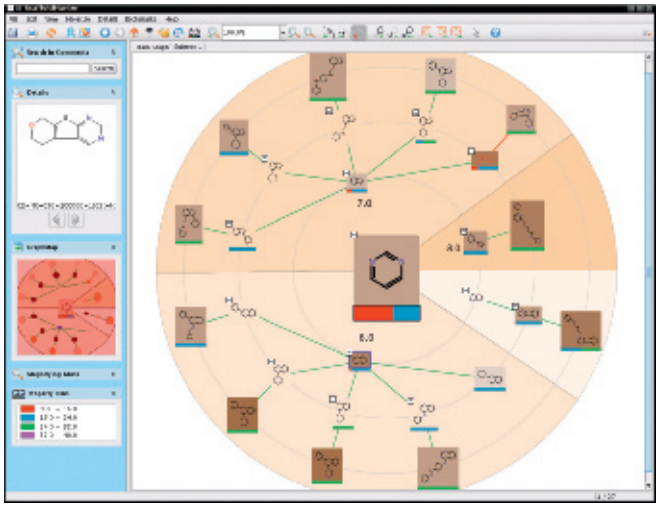
Ribosomes are the protein factories of cells, following a specific plan in producing the proteins needed for life. More than 20 years ago, Ada E. Yonath succeeded in deciphering this plan, as well as the structure and function of ribosomes, using crystallographic techniques. She was a pioneer in this field and had to develop the appropriate methods herself. The breakthrough came in 1995. By this time, ribosomes had already been captured on film. However, it was Yonath who, by inserting "signposts" – using iridium and mercury compounds to mark specific points in the ribosomal subunit – succeeded in making the data and images genuinely readable and thus meaningful. In doing so, she opened the door to the study of these cellular protein factories.



Award-winning scientist: Ada E. Yonath received the 2009 Nobel Prize for Chemistry.

Navigating the Molecular Ocean

Tracking down new active agents to help in the fight against cancer and malaria may soon become easier – thanks to a computer program called Scaffold Hunter. Scientists at the Max Planck Institute for Molecular Physiology and their colleagues at the Universities of Frankfurt and Eindhoven, as well as at the University of New Mexico in the US, are using this program to speed the search for suitable substances.



Family tree of active agents: The Scaffold Hunter program helps identify new candidate substances.

Chemical space contains an estimated total of as many as 10,160 different molecules. However, only a few of these – perhaps 1,060 molecules – are potential active agents. Identifying these islands of biological activity in the ocean of possible compounds is a difficult task. The new navigation system generates a map of chemical space based on structural criteria that it then uses to locate biologically active compounds. Scaffold Hunter can also be used to predict new candidate agents that do not occur in nature.

The scientists concentrate on the medically relevant section of chemical space in which molecules contain ring-shaped structures. To do this, they reduce the molecules to their characteristic scaffolds. Scaffold Hunter then arranges these structures in a kind of family tree based on their similarities: the program assigns smaller "parent" scaffolds to each scaffold by gradually removing rings from the original "child" scaffold. This generates innumerable "parent-child relationships" – structurally related molecules of varying complexity. The advantage of this is that chemically similar compounds are very likely to display similar biological activity.

Photos: Scaffold Hunter (bottom), Max Planck ribosome structure research group (top)

An Attack on Science

In July this year, the young Egyptian Marwa El-Sherbini was stabbed to death inside the district court building in Dresden. In a vain attempt to save her, her husband, Elwi Ali Okaz, a doctoral student at the Max Planck Institute for Molecular Cell Biology and Genetics, suffered serious injury. The Max Planck Society was utterly dismayed by this act of racial intolerance. Our thoughts and sympathies remain with the family, especially the three-year-old son who was present in the courtroom.

This murder in Dresden gave us all pause for thought and for deeper reflection. Some foreign scientists put aside their timidity and spoke – some for the first time – about the resentment they encounter on a daily basis. Our institutes are becoming more aware and sensitive to discrimination against foreigners, whether in their search for accommodation or in dealing with immigration authorities.

Flowers in memory of Marwa El-Sherbini. The young Egyptian woman was stabbed to death in the district courthouse in Dresden.

More than any other German scientific organization, the Max Planck Society is internationally oriented: a third of all Directors hold a foreign passport; 80 percent of postdocs and almost half our doctoral students come from abroad – from China, India, Russia, South and Central America, Italy, the US, France and Poland. Day in, day out, our institute laboratories and libraries are the scene of intercultural and highly successful research.

Indeed, we have expended considerable effort in recent years to encourage this. Our visitor advisors provide excellent, caring support, and their work is reinforced by the international offices already established at some institutes. The assistance they provide ranges from finding suitable schools, accommodation and language courses to opening bank accounts and addressing problems of integration. Still, we have to admit that simply providing optimum working conditions and grants for a global scientific elite is not enough.

Jonathan Howard, himself an Australian and Director at the Max Planck Institute for Molecular Cell Biology and Genetics, confirms that Saxony enjoys a good image worldwide; the institute actively seeks to recruit young scientists with the promise of living and working here in Dresden. However, he was incensed that, during the election campaign for the state parliament, his Chinese, Indian and Scandinavian staff were, on their way to work each day, forced to pass dozens of NPD placards promoting racism. He and his colleagues thus took their protest straight to the parliament of Saxony.

We must not close our eyes to the fact that xenophobia is becoming a negative factor for those considering relocating to Germany. According to a recent study by the University of Halle-Wittenberg, it is actually growing harder and harder to recruit skilled foreign workers in regions such as Thuringia, Brandenburg and Saxony. But xenophobia is not an East-German phenomenon.

Nevertheless, a range of studies show that, 20 years after the fall of the Berlin Wall, East Germans still feel at a distinct disadvantage compared with their Western counterparts. For this reason, xenophobia, Islamophobia and racist attitudes are far more widespread here than in the former West Germany, as stated in a parliamentary report in July 2009.

But there are instances of xenophobia in Western Germany, too, often manifesting itself as day-to-day racism. Examples include the difficulties our staff members have encountered in finding an apartment, from the dark-skinned Indian and his family in Hamburg to the single Muslim male in Stuttgart; and the employee in Heidelberg whose black South African roots provoked an attack by drunken youths. Thus far, our institutes have responded on a case-by-case basis. The incident in Dresden has caused us to reconsider this position. An initial discussion was thus held in mid-August with foreign scientists working

Photo: OH

at Max Planck locations, and clearly underscored the explosive nature of the current situation.

In the future, we must do more at the institute level to ensure that our foreign guests feel comfortable, even outside of our Max Planck Institutes. Consideration must be given to establishing more international offices, as well as to providing welcome packages, intercultural training and expanded professional training for our visitor advisors. It is also beneficial to mutual understanding if foreign scientists who intend to remain in Germany for an extended period also speak the national language and become familiar with the idiosyncrasies of German culture. To this end, we intend to introduce Welcome Days. We also intend to plead our case at the city, state and federal levels – gladly in concert with other scientific organizations.

We regard respect for each other's culture, tolerance of each other's religion and deference for each other's skin color as fundamental conditions for the shared research we aim to promote on a sustained basis. Not least because of our history, the world has a keen and sensitive eye for the way foreigners are treated in Germany. We proved convincingly that Germany is an open-minded and hospitable country when we hosted the soccer World Cup three years ago. It would be wonderful if we could now pick up where the World Cup left off.

Peter Gruss,
President of the Max Planck Society

On the Net

Climate Change Time Line
Is climate change a purely modern phenomenon, or has it always been a part of the Earth's history? How great an influence does mankind have over the climate? In a series of events held by the Max Planck Institute for Chemistry and the Geocycles Research Center at the Johannes Gutenberg University, Mainz, 12 scientists will be leading the discussion. Among them, Tillman Spohn of the German Aerospace Center will be describing how a life-supporting climate came to develop on Earth. Besides the role of the Sun and aerosols, the program will also address the risks of global warming: "Can we actually stop climate change?" Marc Laurence of the Max Planck Institute for Chemistry will explain the rewards and risks of geoengineering – a branch of research that endeavors to halt catastrophic climate change through targeted intervention in the environment. The website set up by the organizers offers an overview of the events, as well as an opportunity to view the presentations in video form.
http://www.klimazeitreise.de

Research Live
In November, the New Technology Center (ZNT) at the Deutsches Museum in Munich launched a unique platform for current science and technology topics. The Max Planck Society is among those taking part. Temporary island displays on topical subjects, presentations by partners in industry and science, a forum and two large areas for special exhibitions are grouped around a permanent core display devoted to nano- and biotechnology. The theme is "Transparent Science," and visitors can not only carry out experiments themselves in a variety of laboratories, but also watch scientists "live" as they go about their work. The following website (in German only) offers a taste of what visitors can expect:
http://www.deutsches-museum.de/ausstellungen/neue-technologien

Election Blog
Doctoral students with an interest in university and science policy will find little to satisfy their curiosity in the governmental programs of the political parties – and yet they constitute a substantial body at universities and research institutions. Reason enough for the Max Planck Society's PhDnet to dig a little deeper. Together with Helmholtz Juniors and the doctoral student network Thesis, they sent a whole list of questions, in the run-up to Germany's federal parliamentary elections, to the SPD, CDU, FDP, Grüne and Linke parties requesting information on four issues: "science as a career", "science in society", "doctoral student education" and "science communication". After the elections, the parties are measured against their promises. The parties' replies and a discussion of them are available at
http://jrresearchersgermany.wordpress.com/

Photo: Antje Meinen

Demographic Change:
A Major Political Problem Zone

Increasing life expectancy on the one hand and low fertility rates on the other: That demographic change will affect society has become fairly common knowledge. But what is far less well known is what consequences this age structure will have for social policy decisions.

TEXT **HARALD WILKOSZEWSKI**

Before the election is after the election. This is particularly true for the major issues of our time. In addition to the two megatrends climate change and globalization, demographic change is at the top of the list of issues that German politicians must confront. The effects of a continued rapid increase in life expectancy, coupled with perpetually low fertility rates and changing family structures, will also pose key strategic and substantial challenges for the agenda of the new German government.

In terms of strategy, for example, there is the question of which basic policy approaches are the most promising: Should government attempt to influence the population directly, or wait until demographic processes reach equilibrium naturally?

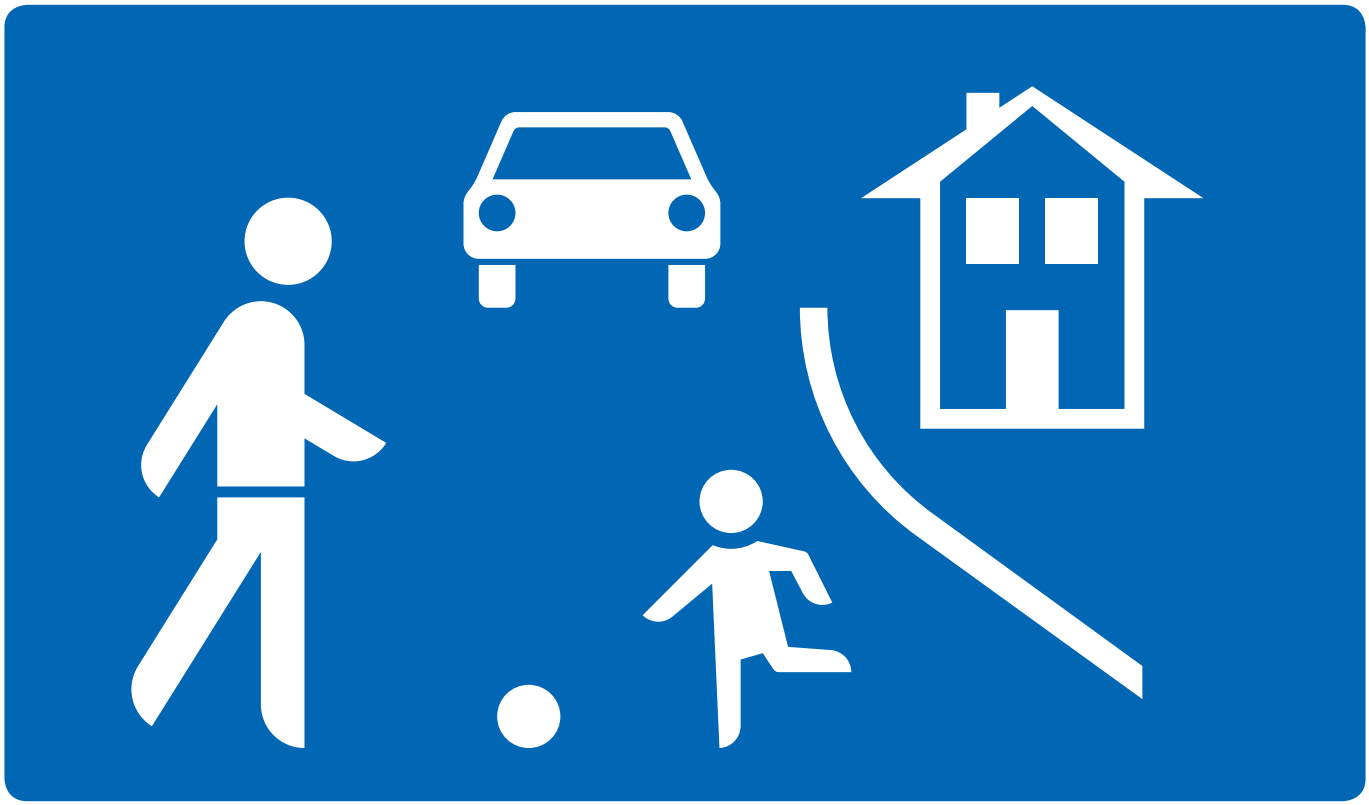
Should governments attempt to influence the population directly?

And as regards specific policies, the main issue is how individual areas of the social system will be affected, such as pensions and health care. Although most Germans have by now heard of demographic change, it seems prudent to take another look at the main aspects of these far-reaching change processes within the German population.

Since 1840, the international record life expectancy has risen with remarkable regularity by 2.5 years each decade. In other words, we get a three-month "bonus" for each year we are alive. Japanese women currently hold the record, with a life expectancy of 86 years. Since the end of the Second World War, the trend in Germany has developed nearly in parallel with the international trend; German women can expect to have an average lifespan of over 82 years.

This development is due primarily to medical progress and improvements in hygiene and nutrition, which drastically reduced the high infant mortality rate to its current extremely low level. All further increases in life expectancy are thus related to a reduction in the mortality of higher age groups.

The extent to which this so-called remaining life expectancy can, even among the very old, be influenced by improving their living conditions is clearly evident in the example of German reunification. Just a few years after the transition to a new system that greatly increased the level of medical and other care in East Germany, the probability of death in the age groups 70 years and older in East Germany approached or even dropped below those in West Germany.



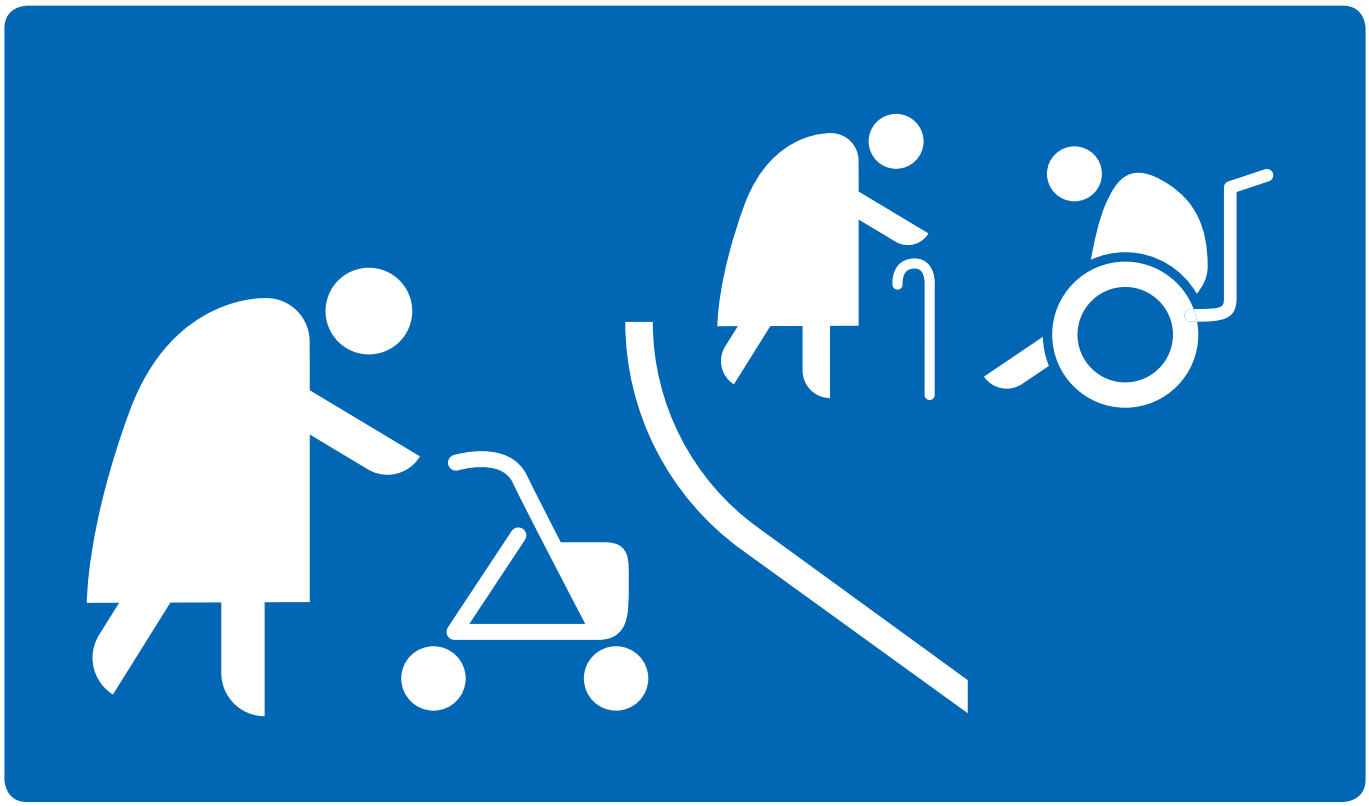


Illustration: OH (above); designergold (below)

There is no evidence that this trend will abate in the still young 21st century, so if the historical time series is extrapolated to 2050, we see life expectancy rising to over 92 years. A girl born today thus has a good chance of reaching the age of 100 – a feat much of the world's population once considered impossible. Planning for such a lifespan will be one of the core challenges of demographic change – for individuals, society and governments alike.

The observation that, for decades, far fewer children have been born in Germany than are needed to replace each generation is not news. For replacement to occur, each woman would have to have an average of 2.1 children; in 2008, however, this number was just 1.36 (for comparison: in 1860, the figure was about 5 children for each woman). However, so-called tempo effects – that is, the fact that couples are postponing the realization of their desire to have children – mean that this figure underestimates the actual fertility rate.

Increasing childlessness will lead to permanent changes in traditional family structures.

For example, for women born in 1958, who are no longer in the reproductive phase, the actual number of children born is 1.6. However, this means that there is still a nearly 25 percent reduction in each subsequent generation. The latest calculations of the Federal Statistical Office – now based for the first time on reliable data for Germany, thanks to new questions in the microcensus – show that this is due mainly to Germany's high childlessness rate. While the number of children per mother has remained relatively stable, the share of childless women has risen, and is currently 21 percent in the 40- to 44-year-old age group.

Together, increasing life expectancy and low fertility rates lead, initially, to an aging population. In Germany, this process is advancing relatively rapidly in international comparison. It can be expected that the share of over-65-year-olds in the total population will double by 2050, to one-third, while the group of 15- to 64-year-olds will shrink 20 percent in the same period. These shifts will make additional reforms necessary, especially in the areas of employment and pensions.

The public debate often ends with these findings on the effects of demographic change, and doesn't account for the fact that increasing childlessness in the country will also cause lasting changes in traditional family structures. A growing share of people will remain without children or grandchildren. Conventional points of contact between the young and the old will thus become scarcer.

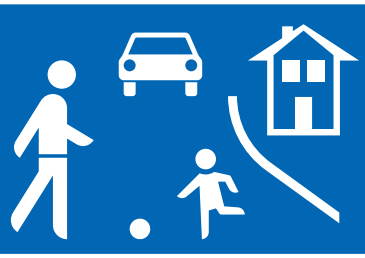
Furthermore, assuming divorce rates remain high, we can expect that partnerships will change form, with fewer people in older age groups still living in a traditional marriage. Successful social and societal policies for the future should therefore also include new family forms in their reform approaches.

A brief look at how the causes and effects of demographic change are being dealt with at the political level suggests that most efforts are still aimed at trying to stop population aging, or at least at slowing it down. This becomes especially evident when the underlying reasons for the most recent changes in family policies are subjected to closer analysis.

The parental leave benefits introduced in 2007 – with an annual cost to the budget of four billion euros – are based on a central paradigm shift in German family policies. This shift was brought about in 2004 by a paper for the Federal Ministry of Family Affairs entitled "Sustainable family policies dedicated to active population development." The stated "meta-goal" of this concept is "to increase the birth rate." This implies nothing less than a complete departure from a principle that has been upheld for decades: no population policies. After all, in a modern, democratic nation, family and population policies differ only in their formulated goals, not in the measures they prescribe.

Family policies see potential parents as subjects to be supported in implementing their decisions. Population policies, on the other hand, are aimed primarily at directly influencing demographic processes, and thus make people the object of political measures.

Photo: OH



Apart from this normative connotation, the parental leave benefits did indeed have a welcome effect. For example, more fathers than expected took advantage of the generously paid leave to raise their children. However, these benefits have not yet resulted in any sustained increase in the fertility rate, which has clearly led to pressure by the media on political leaders. Looking at the effects of family policy measures in other countries, though, it is no wonder that the meta-goal has not yet been achieved.

The case of Sweden, for example, shows that parental leave benefits are just one of a whole range of variables, and that the impact of such benefits on the fertility rate must be seen in connection with such factors as overall economic development and female labor force participation (MaxPlanckResearch 3/2005, p. 70 ff.).

In Germany, a clear mandate of the country's Basic Law and continual reminders from the Federal Constitutional Court regarding the need for family support make it more important than ever that parents and children be provided with adequate assistance. However, a policy that implements these requirements, when the actual goal is to increase the fertility rate, could result in frustration. Moreover, even a lasting increase in the fertility rate to 2.1 children for each woman starting today would reduce population aging only slightly by 2050. This has to do with the sluggishness of demographic processes: a child born today won't have children of his or her own for another 25 to 30 years.

It is thus fair to say that à la carte political control of population structure is hardly possible. A promising political strategy for demographic change should therefore address the question of how the country's various social and economic segments should prepare for population aging. There is plenty of room for creative concepts.

Demographic change can certainly be considered a major political problem zone. It affects, like almost no other phenomenon, practically all areas of politics: education, labor, health care, family, housing construction – and the list could go on, as evidenced by examples from the labor market, the health care sector, and intergenerational relations.

We are already seeing a shortage of skilled professionals in some fields: Employers can't find enough suitable applicants to fill the available positions. The shrinking of the labor-market-relevant age groups could further intensify this problem. The "Rostock Indicator" developed by the Max Planck Institute for Demographic Research shows that, if age-specific activity rates and productivity levels remain constant, the potential workforce in Germany will shrink nearly 9 percent by 2025. This decline could be absorbed by boosting the currently low activity rates in the higher age groups (MaxPlanckResearch 3/2006, p. 14 ff.).

> The potential workforce will shrink nearly 9 percent by 2025.

In an OECD comparison, Germany is in the lower third in terms of labor market participation of persons aged 50 to 64 years. Supporting the employment of older persons hinges on appropriate training throughout their careers. But here, too, Germany ranks near the bottom in international comparisons, since the direct annual cost of training measures – an average of 237 euros per employee in 2005 – constitutes only a small portion of total labor costs.

For the generations born today, the development and promotion of concrete measures for lifelong learning will be even more important: It can be expected that a large share of these people will have to plan for a significantly longer lifespan than today – in some cases up to 100 years. The existing, rigid concept of "education, career, retirement" would mean, for many, a retirement phase of more than 30 years. A social system that is defined largely by labor market participation will not be able to support such life courses.

Action is also needed in an area that is already a constant focus of political reform discussions: health and nursing care. Since the probability of needing nursing care increases with age – in Germany, 34 percent of men and 53 percent of women over the age of 85 required nursing care in 2003 – it seems that one of the first threats of population aging is a steep rise in health care costs. But demographic studies in-

dicate that the years we gain due to increasing life expectancy will not be spent entirely in sickness. People are aging to a considerable extent in good health, so that, on average, 65-year-olds today are much fitter than their counterparts from 20 years ago.

Nevertheless, even under the optimistic assumption that all additional years of life will be healthy ones, the need for nursing care will increase sharply by 2030: by 20 percent for women, and by 79 percent for men. If we assume that the number of years of nursing care needed will increase in proportion to the gain in years of life, then the figures would be 39 percent for women and 127 percent for men. These scenarios make it clear that we must promote health care policy measures that boost the chances of aging in good health.

Germany lacks a population-wide strategy for health prophylaxis.

Preventive approaches are key here. Finland is one of the frontrunners in Europe, having achieved some clear successes with large-scale prevention programs in the area of cardiovascular disease and, most recently, diabetes. Physicians have decried the fact that Germany lacks such a population-wide strategy for health maintenance.

A first step in this direction was taken at the federal level in early 2005, with the drafting of a prevention act. The proposal provided, for example, for the establishment of a national prevention council and the development of binding prevention targets. With the coalition changes that took place in late 2005, the initiative was included in the agreement between the ruling parties. However, due to certain differences, especially regarding the financing strategy, the political negotiations essentially came to a halt in 2008.

In addition to the discussions on the usual political subjects, such as labor and health care, debates over demographic change now also define the broader discourse on social policy, especially regarding the future relationship between the generations (MaxPlanckResearch 2/2007, p. 54 ff.). In this context, it is frequently assumed that, in modern welfare states, a growing share of older people in the total population limits the scope for future social policy reforms. This is due, for example, to the fact that the elderly consistently have higher election participation rates. In addition, forecasts show that, in 2050, half of the German electorate will be over 56 years old.

Citing demographic change, German policy makers have recently introduced several key political reforms with the goal of expanding government support for the younger generation (most recently through parental leave benefits). For the older generation, on the other hand, the tendency was to take advantage of the financial savings potential (such as by not increasing pension benefits). With a growing share of seniors, such a policy mix could prove to be unsustainable.

If the political preferences of older people for public transfers between generations – such as child benefits or pension benefits – turn out to differ from those of younger people, this could indeed, in an aging society, complicate the political decision-making processes.

Research to date has seldom been able to detect such an age effect, particularly due to limited data availability. Most surveys on intergenerational relationships focus mainly on questions relating to private transfer payments, or in other words, support potential within the family. Questions about political attitudes toward public transfers, on the other hand, are usually restricted to opinions about the general responsibilities of the government with respect to the various age groups.

Because all (age) groups, especially in Germany, generally consider the socio-political responsibility of the government to be very high, it is nearly impossible to detect any potentially existing age effect based on these questions. The bulk of scientific studies – which also form the basis for decisions by Germany's policy makers – thus regard the theory of a conflict for resources between the old and the young as unproven.

However, the latest studies published by the Max Planck Institute for Demographic Research, which are based on new data, reach a different conclusion. The surveys, each covering several thousand respondents, also explicitly included questions concerning their support or rejection of concrete social policy reforms,

Illustration: designergold

for example, in the form of 13 family policy measures. Such an approach makes it easier for respondents to consider the potential impact of policy measures on their own lives (or those of their children or parents), their financial security or their possible courses of action.

The analysis of the data clearly shows that age effects do occur when it comes to specific policy reforms. Older respondents, for instance, have a much lower tendency than younger ones to support transfer payments to families (child benefits, tax breaks for parents). Parenthood and grandparenthood were identified as additional major influencing factors.

(Grand)childless respondents likewise showed a much lower tendency to advocate transfer payments to the younger generation. In combination with the higher voter turnout of older citizens, population aging and the growing share of childless people could impede the future decision-making processes in individual social policy domains.

We are already seeing concrete indications of increased conflicts between different demographic groups. For example, the decision by the federal government to expand child care is creating problems in some major German cities: In Hamburg and Munich, more and more residents are fighting the required rezoning, citing the noise disturbance caused by children. Municipal authorities are forced to actively support owners of these facilities in court proceedings, drawing on external expert opinions. Despite these efforts, some day care centers have already had to close due to successful lawsuits.

These examples may be just individual cases, but they clearly show the importance of demographically mixed neighborhoods. Spatial segregation of young and old, of parents and the childless, encourages potential conflict lines, as regular points of contact are then lost – and without them, the exchange required for mutual understanding and tolerance cannot take place.

The social policies of the future must take greater account of these potential divisions. Furthermore, policy makers should take seriously the different preferences of various groups in society, and focus more closely on political mediation. Only then can they gain the necessary support within the population for essential social and demographic reforms. ◂

Photo: Private

THE AUTHOR

Harald Wilkoszewski has been a staff member at the Max Planck Institute for Demographic Research in Rostock since 2003, where he helped establish the "Laboratory of Population and Policy." His research focuses primarily on the effects of demographic change on political decision-making processes.
In November 2009, Wilkoszewski was appointed Scientific Coordinator of Population Europe: The European Population Partnership, a network of 21 leading demographic research institutes in Europe. In addition, in 2008, Wilkoszewski became Fellow and Head of Working Group at the New Leadership Foundation in Berlin, a cross-partisan think tank.

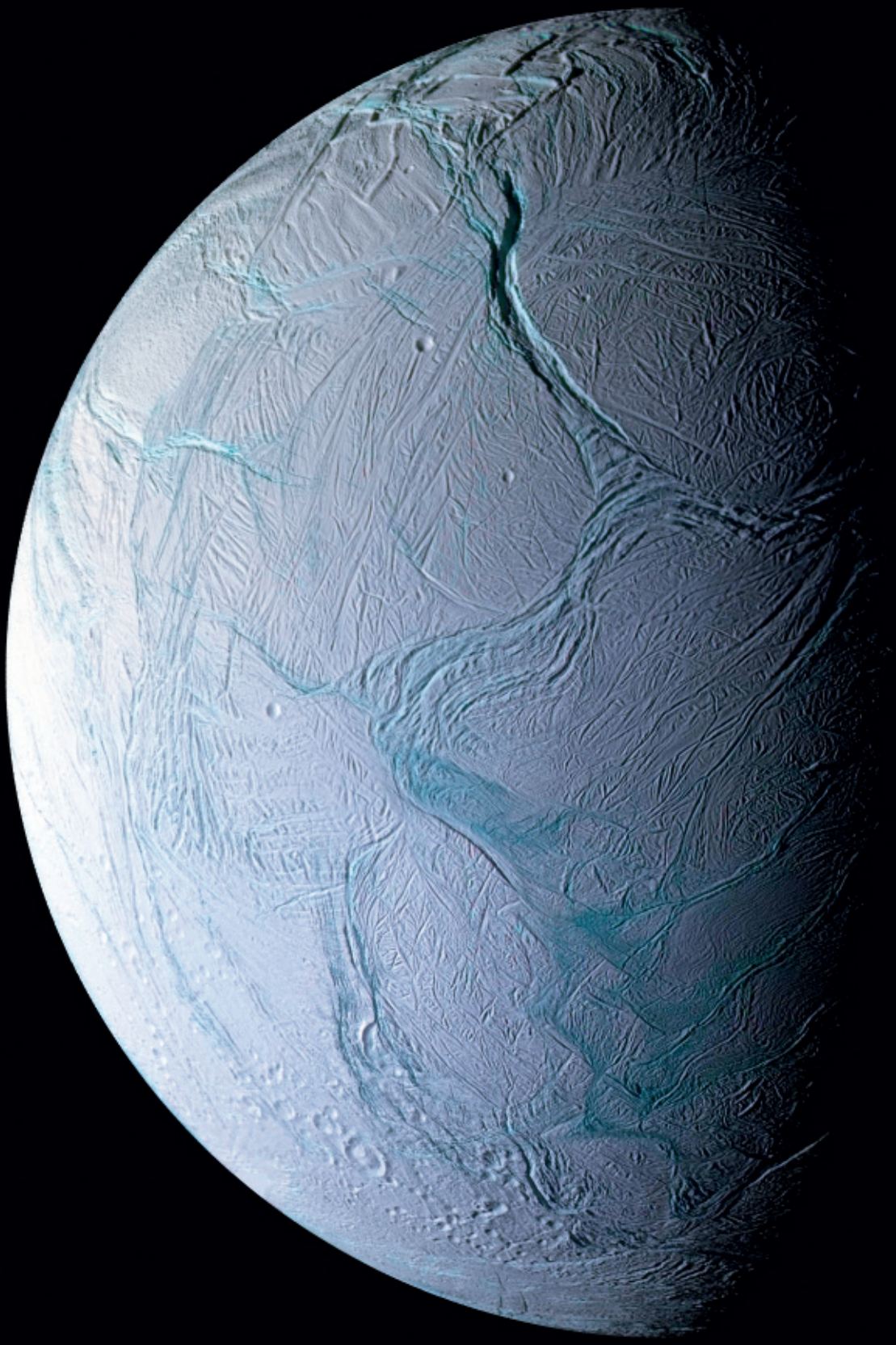


Photo: NASA/JPL/Space Science Institute

The old moon and the sea: The researchers suspect there is an expansive body of water under the icy crust of Saturn's satellite Enceladus.

The Search for the **Elixir of Life**

Whether under the midnight sun of Mars or in the eternal twilight of Saturn's moon Enceladus, researchers are on the trail of water in our planetary system. Scientists from the **Max Planck Institute for Nuclear Physics** in Heidelberg and **for Solar System Research** in Katlenburg-Lindau are also on board.

TEXT **THORSTEN DAMBECK**

Hardly anybody knew this tiny satellite. It had never particularly distinguished itself since its discovery 220 years ago. Only experts knew that Enceladus was one of the moons orbiting Saturn. Even the two *Voyager* probes that passed by for a fleeting visit over two decades ago did not detect anything unusual. But the extensive studies carried out by *Cassini* – the unmanned scout that has been orbiting the ringed planet since 2004 – have shifted Enceladus into the researchers' focus. The joint American-European space probe regularly flies over its ice-covered landscapes and has discovered that this mini-moon, scarcely 504 kilometers across, is literally hiding something.

At Enceladus' south pole, huge plumes of water vapor and ice particles shoot into space. This spectacle originates in several ground fissures measuring more than 100 kilometers in length, or to be more precise, at active locations within these fissures. Planetologists call them tiger stripes. These gates to the underworld of the moon are unusually warm, in some places exceeding the temperature of the surrounding areas by more than 100 degrees. The question is, is there also liquid water below the surface?

SCIENTISTS PRICK UP THEIR EARS AT THE MENTION OF WATER

Planetologists always prick up their ears when they hear talk of water in the solar system. Liquid water is a kind of elixir of life, after all – a precondition for life as we know it on Earth. It is quite conceivable that it plays or played a similar role on other planetary bodies as well. >

According to the current state of our knowledge, however, the surfaces of moons and planets have been ruled out; rivers and oceans have been able to form permanently only on Earth. This is because only our home planet orbits the central star within just the right range. Slightly closer, at about 90 percent of the distance from the Earth to the Sun, the temperatures would already exceed 100 degrees Celsius. In the opposite direction, the temperature drops: even on Mars, all the water present in the past has frozen to form ice.

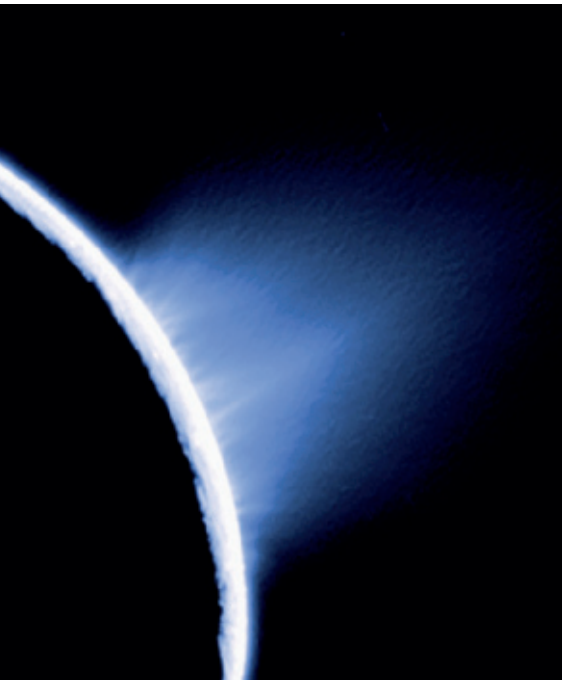
Below the fissured ice desert of Enceladus, in contrast, it seems to be warm enough; the most recent evidence for this was provided by the *Cosmic Dust Analyzer* (CDA) aboard *Cassini*. The instrument discovered particles of water ice that also contain the element sodium. "They were found in the E-ring of Saturn – a ring of dust that is much larger but also much weaker than the better-known A-ring and B-ring, which can be seen even with amateur telescopes," says Ralf Srama of the Max Planck Institute for Nuclear Physics in Heidelberg, who heads the CDA experiment.

THE DETECTOR COMES UP WITH A FIRST IN SATURN'S E-RING

"Enceladus traces out its orbit in the E-ring; this small moon is the main source of particles for this ring," says Srama. The CDA weighs about 17 kilograms and is a so-called dust detector. The term "dust" is not used in its conventional sense here. It describes minute particles that buzz about in many parts of the solar system; they are measured in micrometers (thousandths of a millimeter). "The mass spectrometer in the CDA can detect the chemical elements in such particles," explains Srama. The technical predecessors of the instrument had already flown on several space missions, but it was in the E-ring of Saturn that they came up with a first: they caught the frozen salt water droplets of an extraterrestrial ocean – an underground lake on Enceladus.

The sixth largest of Saturn's moons receives only around one percent of the solar heat that falls on Earth. The temperatures on its surface reach an average of minus 198 degrees Celsius at midday. But completely different conditions prevail under the "skin." Recently published model calculations offer a first attempt at explaining why the southern hemisphere is geologically young and active, in stark contrast to the ancient northern hemisphere. It proposes that convection has occurred in Enceladus' ice mantle, with warm ice below the south pole rising and cold ice, probably at the north pole, flowing downward.

Fountains of gas and ice particles shoot into space from at least eight fissures near the south pole of Enceladus.



A model ocean: Below the crust of Saturn's moon Enceladus, minerals from the rock are dissolved in water. Sprayed droplets freeze immediately. As they pass through the fissure in the ice crust, they are enveloped in more water vapor, which freezes onto them, and they are then ejected as dust particles.

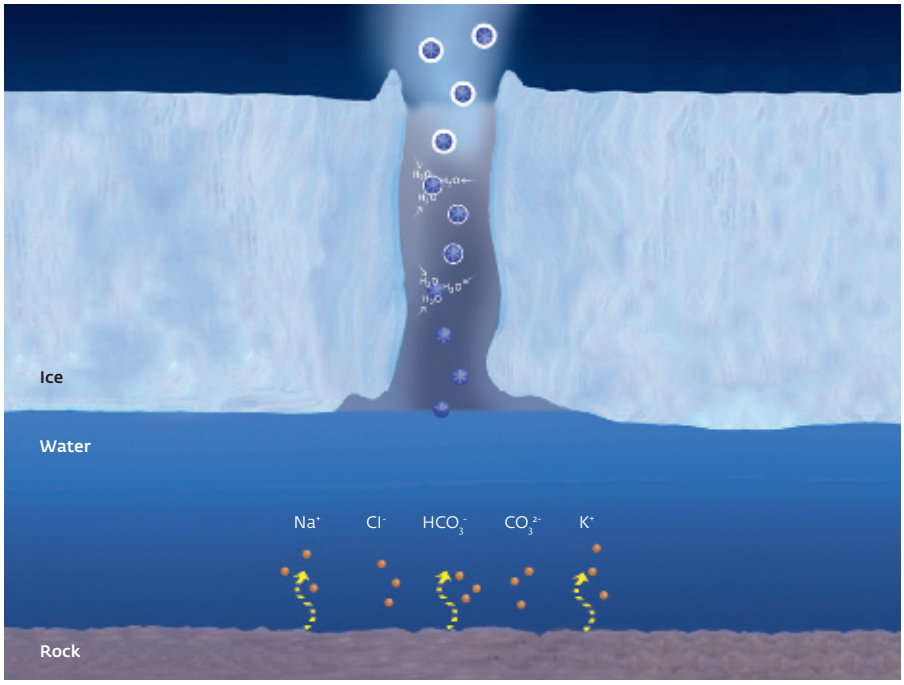


Photo: Cassini Imaging Team/SSI/JPL/ESA/NASA (left), graphic: MPI for Nuclear Physics

A heat source is required to drive such a current. This is probably fed by tidal friction, because the satellite's orbit is slightly elliptical and thus periodically changes its separation from Saturn, which it orbits once every 33 hours. In the gigantic gravitational field of the ringed planet, the tidal forces constantly tug at the moon and give it a thorough kneading, so to speak, thus generating a considerable amount of internal heat.

WHAT CAUSES THE FOUNTAINS TO SHOOT UP?

The researchers puzzle over whether this convection is still ongoing and whether tidal heating alone is sufficient to explain the currents in the ice. In any case, observations show that sufficient heat is still available deep down to keep the water of the lake from freezing and to drive the activity of the fountains.

The most recent CDA measurements show that such a lake must be hidden there. Many years ago, planetologists had already reasoned that, if liquid water really existed below the crust of Enceladus and reached down to the warm rock core of the moon, then sodium chloride and other salts must have been extracted from the minerals there. The alkali metal has now been detected by the mass spectrometer of the CDA instrument.

Valuable piece: The 17-kilogram *Cosmic Dust Analyzer* (CDA). The instrument on board the *Cassini* space probe analyzes the surroundings of the ringed planet Saturn. The dust detector has a turntable to adjust its orientation.

Photo: MPI for Solar System Research

Frank Postberg from the Max Planck Institute for Nuclear Physics has analyzed the data from 1,000 E-ring particles. These are particles with diameters of between one and one tenth of a micrometer – about as small as the particles in cigarette smoke. "All consist mainly of water ice," says Postberg. "Around 6 percent of the particles, however, are different; they contain up to 2 percent salts, mainly sodium chloride. This component, as known as table salt, is also the mineral that is dissolved in the highest concentration in the Earth's oceans."

The spectra also show sodium carbonate, sodium bicarbonate and low quantities of potassium salts. The Heidelberg-based scientist, who came to the planets from chemistry via physics, assumes that these compounds come from a saline lake, because the water can carry along its load of salt to the cold surface only if it is still liquid at depth. When detached as a spray from the liquid surface, the droplets freeze and are carried upward by the vapor stream. Most of them probably fall back to the surface after ejection, but some make it to the E-ring and into orbit around Saturn.

The chemical conditions in the hidden lake under Enceladus's coat of ice are conserved inside the droplets. The vast majority of the E-ring particles investigated, about 90 percent, are very low in salt, comparable with distilled water. Postberg says: "These droplets come from a cloud of water vapor above the lake. They are produced when the steam carried along condenses to particles of pure water ice."

So what is the lake like? "The lake is in contact with the water vapor above it over an area of at least several square kilometers. We can assume there are large, steam-filled chambers that taper like a chimney toward the top," explains Postberg's colleague at the institute, Sascha Kempf, the scientific manager of the CDA experiment. >

Photos: ESA/DLR/FU Berlin (G. Neukum)

This sheet of ice looks perfect for ice skating. The problem is that you would have to travel to Mars to enjoy it. The ice collects at the bottom of a crater some 35 kilometers wide in the Vastitas Borealis plain. Signs of water can also be seen in the image above – cliffs around two kilometers high and covered with ice and dust at the north pole of the red planet.

Today's salt water lake on Enceladus is most probably not a global phenomenon, but limited to the south pole region. A further indication of this is something that *Cassini's* camera has taken a photo of in the surface relief of the south pole: a large depression some 500 meters deep – beneath it could be the lake.

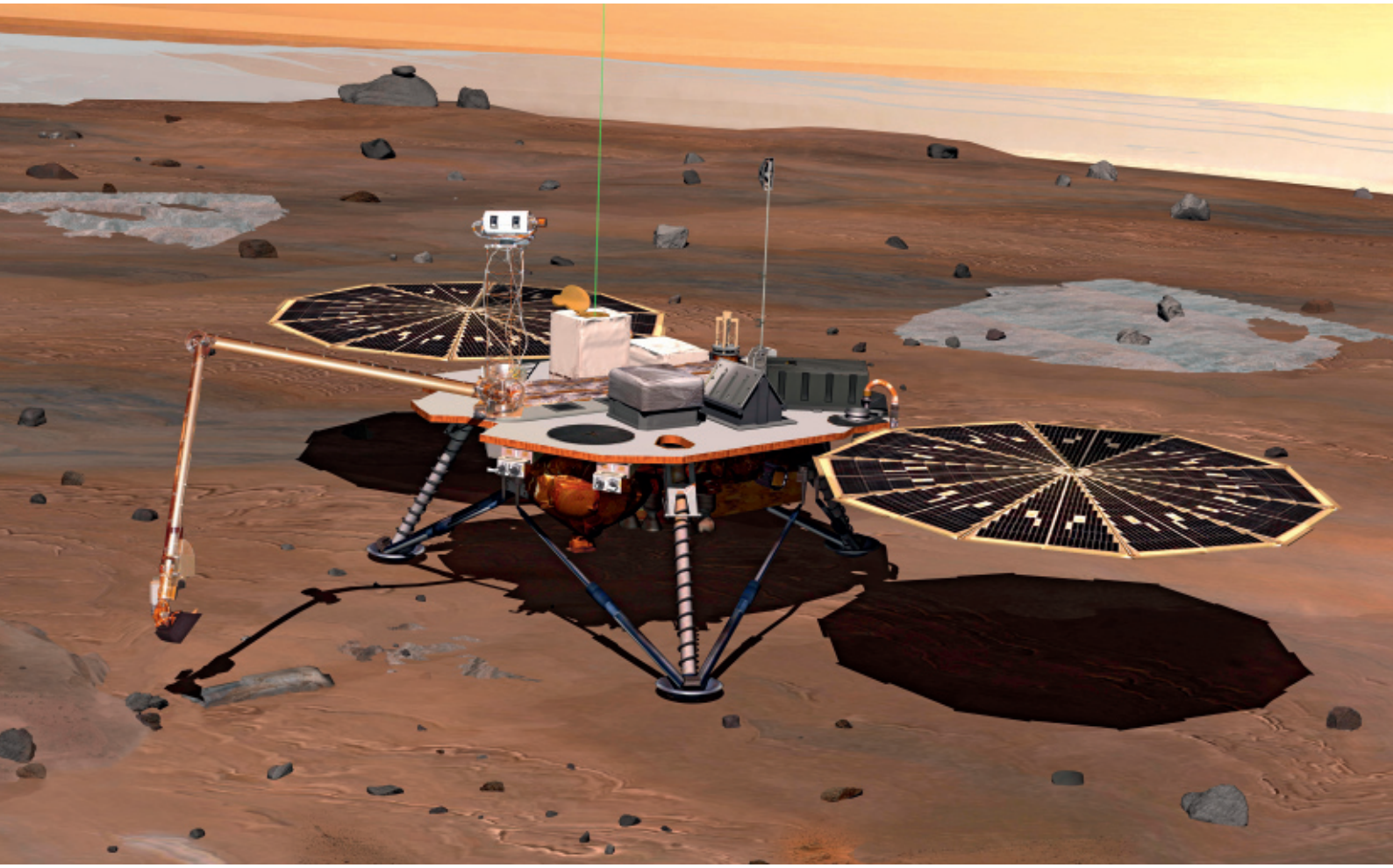
DRY VALLEYS AND ISLANDS AS PROOF OF EARLIER FLOODS

Enceladus is not the first satellite in the icy backyard of the outer solar system to be credited with having liquid water underneath its crust. Back in the 1990s, Jupiter's moon Europa attracted the attention of planetologists. The ocean in the depths there is even believed to have global dimensions. A further two of the four large Jupiter satellites, Ganymede and Callisto, may also hide zones of liquid below their icy crusts.

When scientists dare to look back into the early life of the planets, they quickly come up against the limits of their knowledge. This is no different when it comes to our neighboring planet Mars. Planetologists have known for decades that it was a home to water – even in the liquid form – in its early period. Even after billons of years, huge, sometimes twisting dry valleys with streamlined islands bear witness to the eroding force of the floods prevalent at that time. The remains of deltas are also widespread. They formed when water masses flowed into standing waters such as lakes in the hollows of impact craters. But researchers are still puzzling over whether the young Mars experienced only short, wet phases in its climate or whether the water was present on its surface over long geological periods.

In any case, liquid water can now exist on the surface in the thin and cold gaseous envelope only under particularly favorable conditions and only for a short time. It has not yet been detected anywhere with absolute certainty. Water ice, in contrast, is widespread – at the polar caps and also as ground ice in medium latitudes. Can the ice melt from time to time? If the climate changes, could even local habitable zones form – refuges for potential microbes that may possibly have survived in the icy desert until now?

A possible Martian oasis was the destination of the *Phoenix* space probe with which the American space agency



NASA first ventured into the far north of the desert planet in May 2008. There, too, at 68.2 degrees areographic latitude (roughly the same latitude as Kiruna in northern Sweden), Mars researchers expected to find water ice just below the surface. Unlike *Spirit* and *Opportunity*, the two Mars mobiles that had been in operation for years, the three-legged *Phoenix* was stationary. Its task was to collect various soil samples with its nearly 2.5-meter-long scooping arm and analyze their chemical composition.

The *Robotic Arm Camera* (RAC) from the Max Planck Institute for Solar System Research in Katlenburg-Lindau found the first clues to subsurface ice after only a few days. The device, which weighs a mere 415 grams, was able to take a spectacular picture on which glaring, bright soil layers can be recognized between the foot pads of *Phoenix*. The exhaust jets of the 12 landing thrusters had obviously blown away a layer of covering material about 5 centimeters thick and unearthed the ice.

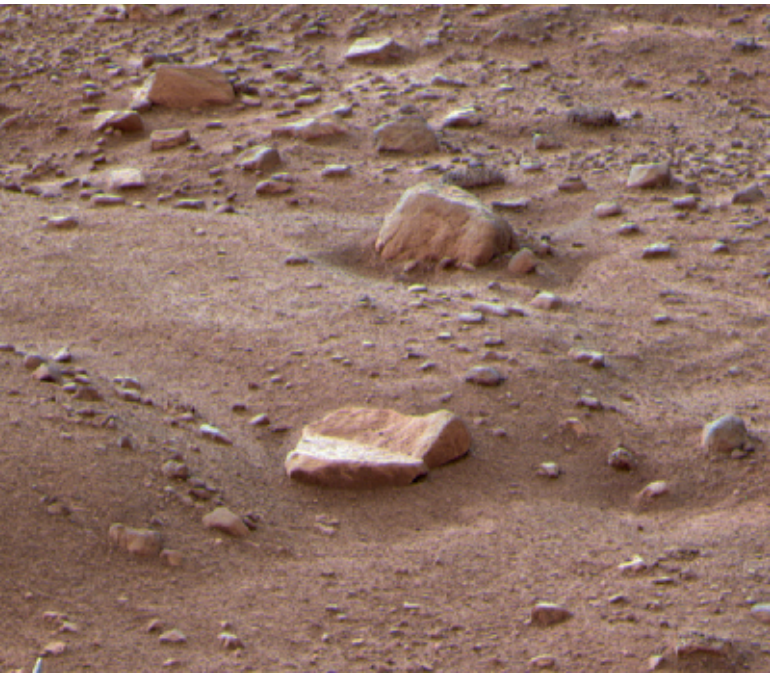
UNDERGROUND ICE IS STABLE OVER LONG PERIODS

The photos of the freshly dug channels showed further proof of ice – more light, sometimes white spots. "Once the ice has been dug out and deprived of its thermal insulation layer, it starts to change," says Walter Goetz, who analyzes the *Phoenix* data at the Max Planck Institute for Solar System Research. Once exposed, the ice starts to sublime – in other words, it evaporates without melting beforehand. Underground, however, it is stable over long periods.

The main task of the RAC was to document the sampling of the scooping arm. The chemical analysis provided some surprises: the *TEGA* instrument (Thermal Evolved Gas Analyzer) aboard *Phoenix* found only small amounts of water ice. In the built-in mass spectrometer it showed up as a gas released as the soil samples were gradually heated. The small amounts of water below 295 degrees Celsius are indicative of a dry soil without ice and without water that adheres to the surfaces of the soil minerals.

This result can apparently be explained with the special sample, because it proved difficult to maneuver the lumpy, icy soil into the *TEGA* ovens. At higher temperatures, which were increased up to 1,000 degrees Celsius, the instrument did find water after all. "This is possibly H_2O that is

Photo: NASA/JPL/UA/Lockheed Martin



left | The *Phoenix* has landed! The Mars probe explored the northern polar region of Mars from May until the beginning of November last year. Instrumentation from the Max Planck Institute for Solar System Research was also on board.

above | Frosty Mars landscape: One of the last *Phoenix* photographs from October 28, 2008 (left). A short time later, the landing craft lost its solar power at the end of the arctic summer, and night temperatures dropped to an icy 89 degrees Celsius below zero. *Phoenix* did not live quite as long as had been hoped, but it gave the researchers a rich harvest – the discovery of water ice, for example, which was exposed by the landing thrusters and photographed with the *Robotic Arm Camera* (right).

Photos: NASA/JPL-Caltech/Univ. of Arizona/Texas A&M Univ. (left), M. Di Lorenzo/K. Kremer/NASA/JPL/MPS/Spaceflight (right)

bound in the minerals of Mars's soil as water of crystallization," explains physicist Goetz. Furthermore, the Wet Chemistry Laboratory looked for soluble substances in the soil. The necessary moisture was provided by water from Earth – *Phoenix* took it along specifically for this purpose.

Both instruments revealed some remarkable soil chemistry: for the first time, they measured an alkaline pH value of about 7.7. At the equator, where *Spirit* and *Opportunity* are exploring Mars, the situation is different. Their soil analyses seem to indicate a more acidic environment. "Perchlorate salts were also identified," says Goetz. These compounds of oxygen and chlorine were quite a surprise. They could hint at the soil having thawed at some time.

Many researchers even consider it possible that the anti-freeze effect of the perchlorate itself could keep water liquid even at temperatures down to minus 70 degrees Celsius. Photos taken by the RAC are also put forward as evidence of this: they show, on one of *Phoenix's* landing struts, small round structures that are interpreted as drops. According to this hypothesis, it is ground ice that, in the final seconds of the descent, was melted by the heat of the landing thrusters and sprayed upward.

A LITTLE BIT OF CALCIUM CARBONATE IN THE SOIL

The *TEGA* instrument also discovered a few percent of calcium carbonate in the Martian soil. Planetologists had long tried in vain to discover it on the red planet. Skeptics argued that, if Mars really had been rich in water for a lengthy period, the carbon dioxide of the gaseous envelope must almost inevitably have formed measurable quantities of calcium carbonate.

Phoenix has now indeed found the carbonate in Mars's soil. Color portrait photographs of a large number of mineral grains are now available, although their chemical composition is still unknown. Some could contain the recently discovered calcium carbonate. The portraits of the tiny particles come from the microscope camera for which the Max Planck researchers in Katlenburg contributed the hardware.

The data from the Canadian weather station on board *Phoenix* also show the role of H_2O on the Mars of today. The back-scattered beam of a laser was used to measure the vertical layering of clouds of ice crystals above the vehicle. When it was mid-summer at the

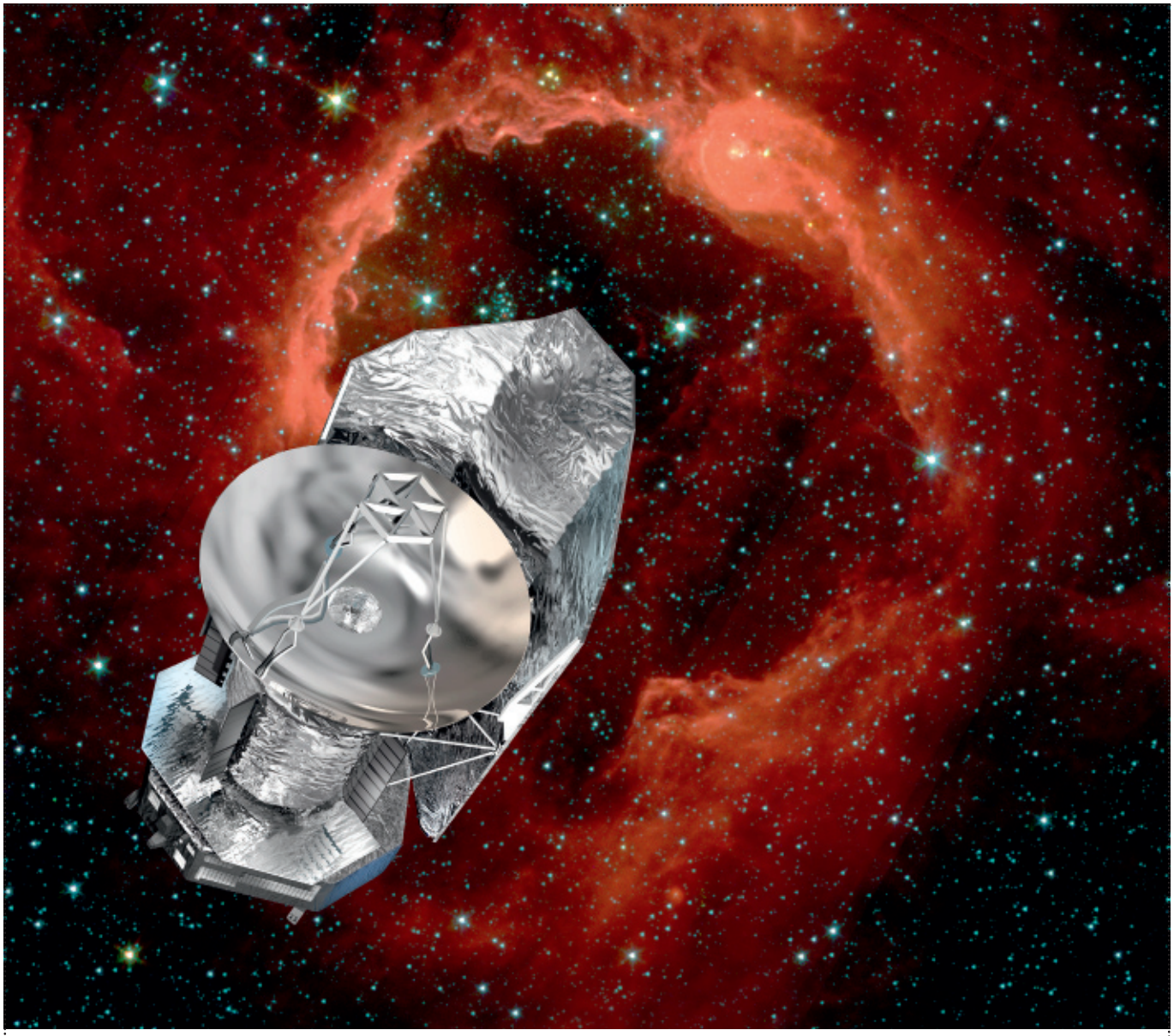


Photo: ESA – D. Ducros, 2009

HERSCHEL HELPS WITH HIFI

Herschel, the European space telescope launched in May 2009, is also going to help with the search for water in the planetary system. Mars, the gas giants and the Saturn moons Titan and Enceladus are on the to-do list. In the case of the gas planets, the researchers will take a particularly good look at their stratospheres. How does the water vapor get there? Although it is assumed there is water in the interior of the gigantic planets, it is unlikely that it can get into the stratospheres. "These atmospheric layers should actually be bone-dry," explains Paul Hartogh, who heads the observation program from the Max Planck Institute for Solar System Research.

However, measurements show that this is not the case. "In Jupiter's case, we suspect the source to be comet ice introduced by impacts," says Hartogh. Other conceivable causes are interplanetary grains of dust that also contain water ice, or, in the case of Saturn, for example, ring particles containing ice. *Herschel's HIFI* instrument (Heterodyne Instrument for the Far Infrared) will make it possible to differentiate between these different processes. HIFI is the most sensitive spectrometer ever built for observations in the far infrared. It was developed in international collaboration. Several Max Planck Institutes were among those involved, under the coordination of the Dutch Institute for Space Research. The instrument will measure the spatial distribution, in particular the vertical profile of the water vapor in the gaseous envelopes of the planets.

landing site, the Mars meteorologists found clouds above an altitude of 10 kilometers.

… AND THE FURTHER OUTLOOK: WIDESPREAD GROUND FOG

Later in the Martian year, the night temperatures on the ground dropped to below minus 90 degrees Celsius. The base of the snow clouds also decreased to an altitude of four kilometers. Moreover, the automated weather station reported ground fog almost every night. During the colder daylight hours, *Phoenix's* eyes could even see the frozen water: again and again, the onboard cameras photographed thin layers of bright frost that disappeared again from the Martian surface as the Sun rose in the sky.

In a recently published article in Nature, the *Phoenix* team comes to the following conclusion: There are growing indications that liquid water periodically exists in the soil of the landing site. The more favorable climatic phases necessary for this could be initiated by cyclic changes in the inclination of the rotational axis of Mars and the parameters of its orbit. There could, therefore, have been phases in the landing site's more recent geological past that were indeed conducive to life.

The *Phoenix* mission has now been completed. It was only the sixth successful Mars landing ever. Naturally, the data from the surface of the red planet is available only for certain points. Nevertheless, Mars researchers are looking for answers to the great questions about the climatic history of Earth's neighbor: Where did Mars's water disappear to and what processes allowed this to happen? Or, if the water is now present only in the frozen state, where are these once considerable quantities of H_2O hiding? The measurements taken by the two identical Swedish *ASPERA* instruments that have been orbiting Mars and Venus aboard two ESA probes for many years are also important in forming a complete picture. *ASPERA* (Analyzer of Space Plasma and Energetic Atoms) can be used to study the processes that lead to water being lost today.

It is clear that, in the upper atmospheric layers, the water molecules are split by the energy-rich UV radiation of the Sun. The low gravity on the relatively small planet of Mars causes some of the light hydrogen atoms to even escape as neutral particles. Things are different on the heavier sister planets Venus and Earth: here, the H-atoms must first be ionized in order to receive an additional kick away from the planet at higher altitudes by the induced magnetic field of the solar wind.

Scientists are putting together the pieces of the puzzle with their measurements. Fortunately, the ESA recently decided to extend the planetary missions until 2012 – because many years of meticulous research still lie ahead before we have a complete picture of the history of water in our solar system. ◂

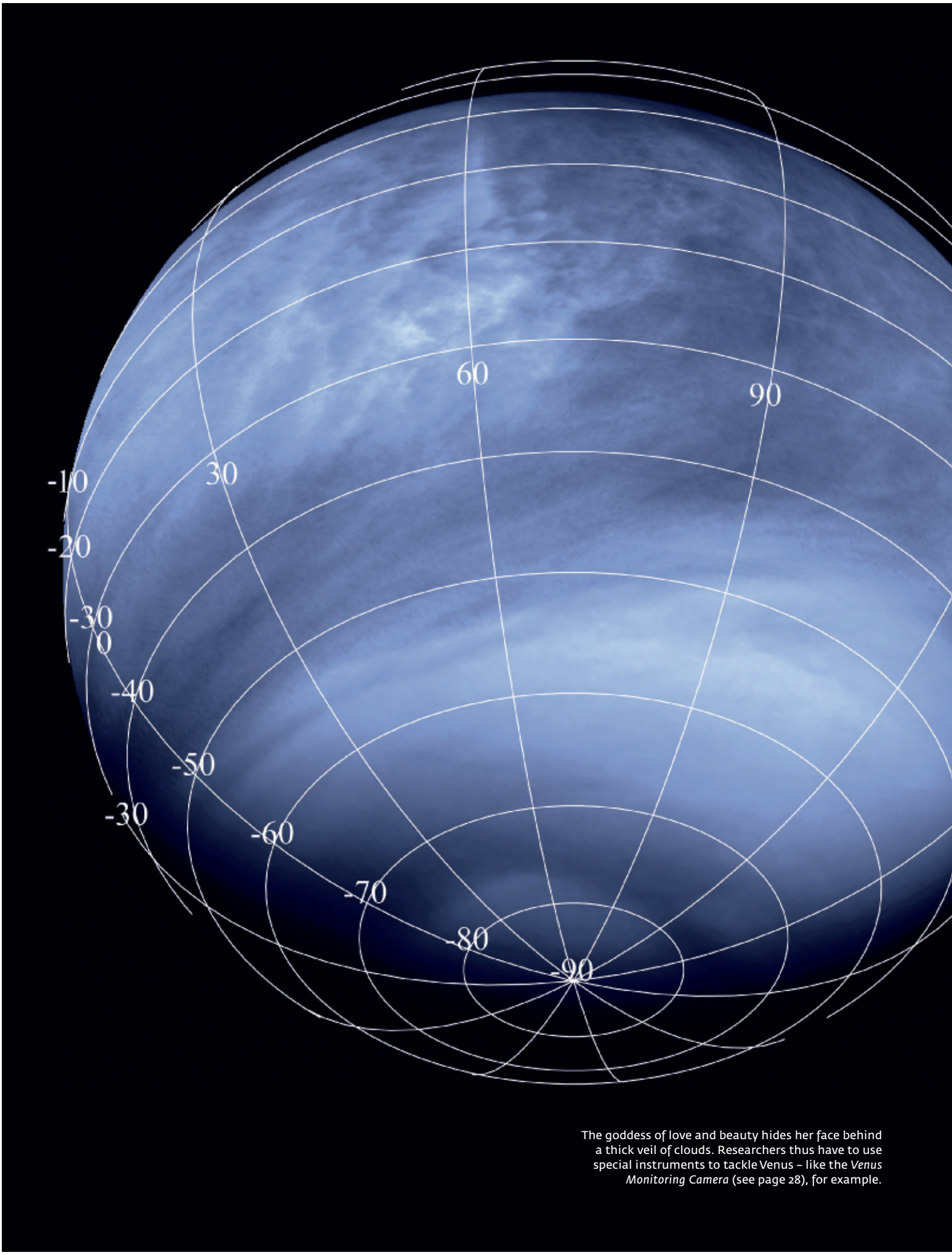
GLOSSARY

Cassini
A probe named after the French astronomer Giovanni Domenico Cassini (1625 - 1712). Launched in 1997, the spaceship – a joint project between the American NASA and the European ESA – has been orbiting in Saturn's system since July 2004. *Cassini* carried *Huygens* on board, the small probe that landed on Saturn's moon Titan on January 14, 2005.

Mass spectrometry
Method of determining the ratio of mass and charge of molecules and atoms. The sample is initially converted into the gaseous state. The gas is then ionized and the ionized particles accelerated in an electric field and analyzed. Mass spectrometry can be used to identify chemical elements or compounds.

Rings of Saturn
They were identified as such by Christiaan Huygens in 1656. It is usual to distinguish seven components, designated A to G. The system has a diameter of 960,000 kilometers and is only a few hundred meters thick. The rings consist of innumerable individual chunks.

Solar wind
Gas that continuously streams from the solar corona into interplanetary space. This plasma contains charged particles – mainly free electrons, hydrogen nuclei (protons) and helium nuclei. The solar wind "blows" at an average of 400 kilometers per second at the Earth's distance and is responsible for the formation of the gas tails of comets, for example.



The goddess of love and beauty hides her face behind a thick veil of clouds. Researchers thus have to use special instruments to tackle Venus – like the *Venus Monitoring Camera* (see page 28), for example.

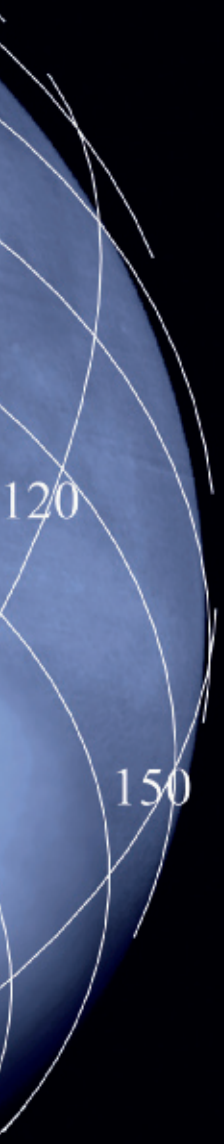


Photo: ESA/MPS/DLR/IDA

The Blazing Hell Behind the Veil

The first European Venus probe has been orbiting our neighbor in the solar system for more than three years: *Venus Express* has a bizarre inferno in its sights. **Dmitriy Titov** from the **Max Planck Institute for Solar System Research** in Katlenburg-Lindau coordinates the mission planning and data analysis.

TEXT **THORSTEN DAMBECK**

If we look at the bare numbers, Venus should really be something like Earth's twin. Its diameter measures 12,100 kilometers, which is 95 percent of that of our planet. The same applies to its mean density (94 percent) and its mass (82 percent). Yet the planet, which is 108 million kilometers from the Sun (Earth: 150 million kilometers) is completely different. Corrosive clouds of sulfuric acid hang in the air on Venus – an almost impenetrable veil behind which our neighbor hides from the far too inquisitive eyes of science. This explains why astronomers were long unable to detect anything with their telescopes in the featureless yellow of the planet's disk. This dearth of information stimulated researchers' imaginations: does it have any deserts, similar to the Sahara, or even tropical rain forests? The first space probes put an early end to such speculations. In a flyby in 1962, *Mariner 2* already made two important findings that put the supposedly twin planet in sharp contrast with Earth. First, *Mariner* detected almost no water in the air surrounding Venus, and second, the US probe reported lethal temperatures on the surface. The hypothesis of the Venusian jungle quickly died.

In 1967, *Venera 4* sent a weather report directly from the hot gaseous envelope. The Soviet probe confirmed the existence of an atmosphere rich in carbon dioxide. From the 1970s onward, several Soviet landers even sent panorama photos from the surface and increased the accuracy of the weather data. The air pressure at the surface is 92 bar – on Earth, one would

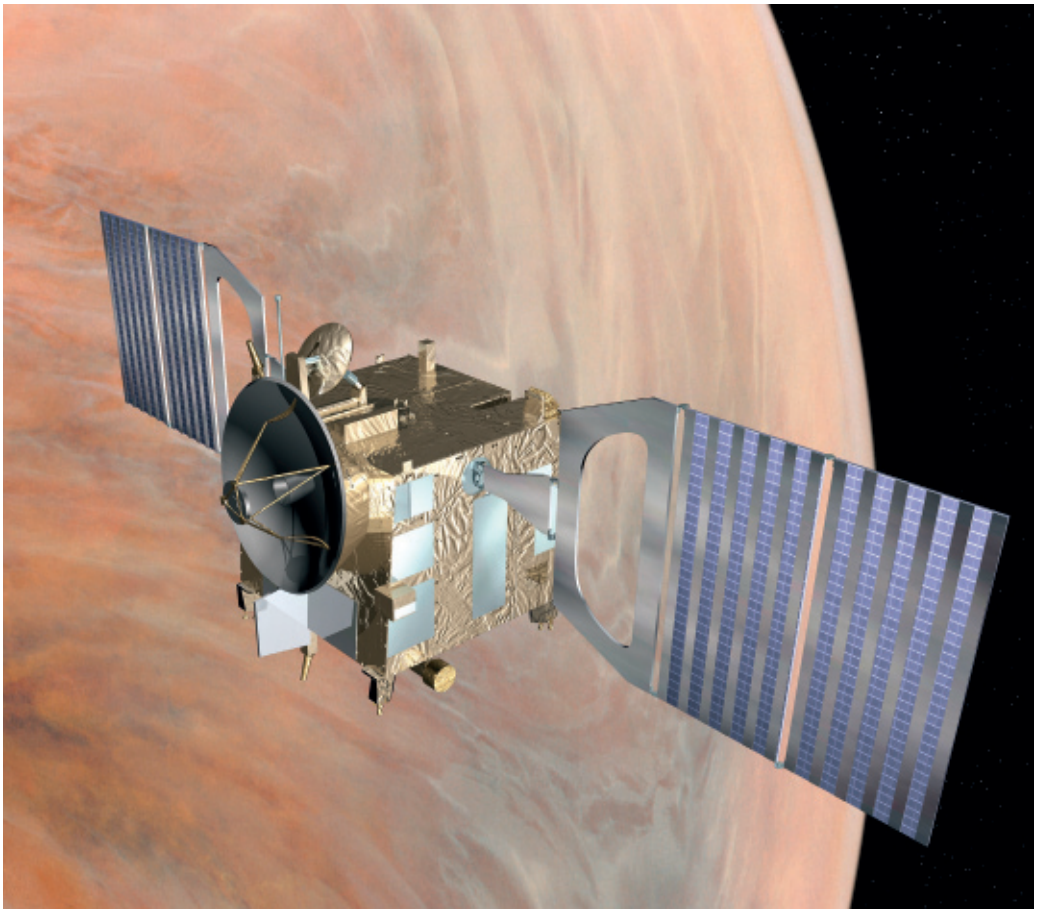
A MONITOR FOR VENUS

A treasure chest for planetologists:
The *Venus Monitoring Camera* provides pictures of Earth's neighbor in the ultraviolet up to the near infrared spectral range.

The project to build the *Venus Monitoring Camera* (VMC) was spearheaded by the Max Planck Institute for Solar System Research in collaboration with the Institute for Planetary Exploration (DLR) in Berlin and the Institute of Computer and Network Engineering at the Technical University in Braunschweig. The compact camera with a weight of less than 1.8 kilograms has a field of view of 17.5 degrees; at the most remote point of its elliptical orbit, Venus fills just about the entire image. The parts of the orbit close to Venus are intended for detailed studies. The resolution varies between 200 meters and 50 kilometers, depending on the distance.

Moving parts such as filter wheels were largely avoided in order to keep the design simple and unsusceptible to technical problems. Images of Venus in four different wavelengths, from UV and visible light to infrared, are simultaneously projected onto the same CCD sensor. Each wavelength uses a certain quadrant of the detector. Even before the photos are transmitted to the board computer, the image data is subjected to initial image processing in the camera.

Photo: MPI for Solar System Research (left), SPL – Agentur Focus (top)



left | Temperatures of around 460 degrees Celsius and the same pressure that occurs 900 meters below sea level make survival difficult even for a robot. That's why views of Venus's surface are rare. The picture on the left was taken by the *Venera 13* Russian space probe.

right | Max Planck researchers play a crucial role in analyzing the data from the European scout *Venus Express*.

Computer graphics: ESA

have to dive to sea depths of more than 900 meters to encounter such pressures. In the stony Venusian desert, the temperatures reach 457° Celsius on average – lead would immediately melt here. And Venusian clouds race at Formula 1 speeds across the overcast sky.

HOW DID EARTH'S NEIGHBOR COME TO BE A HOTHOUSE?

Although more than 30 probes have already reached Venus, many questions remain unanswered: What drives the stormy Venus atmosphere? Why does the atmosphere rotate 60 times faster than the planet itself? Are there active volcanoes still hidden under the dense clouds? And the key question is still open: Why did Venus follow its strange development path to become the hothouse it is today?

Venus Express, the first scout of the European Space Agency (ESA), has been orbiting Earth's neighbor since April 2006. Six instruments including cameras are in action on board to find answers to these questions; they bear witness to the truly European nature of the mission. The Italo-French *VIRTIS* is an imaging spectrometer – in other words, it also works as a camera. It studies the lower atmosphere and the surface. The chemical composition of the gaseous envelope is analyzed by the *SpicaV/Soir* spectrometer under the direction of French and Belgian researchers with strong Russian participation. It uses the light of the Sun and individual stars as it travels through the Venusian atmosphere to probe its structure and composition.

93 KILOS OF EXPERIMENTS

Researchers from Germany probe the ionosphere, atmosphere and surface with the VeRa radio experiment. The Swedish experiment *ASPERA* studies the interactions between the upper atmosphere and the solar wind. Two new developments are also included: the Austrian magnetometer *MAG* and the German wide-angle camera *VMC*, which was developed under the leadership of the Max Planck Institute for Solar System Research (see page 28). The payload totals 93 kilograms. >

This mission has advanced the institute in Katlenburg-Lindau to a center for research into our sister planet. Pictures and measurement data land on Dmitriy Titov's desk on a daily basis. The Russian physicist coordinates the mission planning and the analysis of the scientific data.

Venus Express orbits the planet on a strongly elliptical orbit once every 24 hours, its altitude varying between 250 and 66,000 kilometers. "The elongated orbit means that the instruments and cameras look especially at Venus's southern hemisphere," says Titov. The observation of the atmosphere is facilitated by the fact that the planet shows many details in the ultraviolet (UV), which is not the case in visible light.

Although this has been known for a long time, the planetologists still puzzle over which substance causes this uneven absorption of UV radiation. "The unknown substance is probably hidden in the sulfuric acid droplets of the clouds," explains Dmitriy Titov. In any case, the presence of mysterious material is also a great help, because "it makes it easy to follow the dynamic processes in the Venusian atmosphere in UV light."

How is Venus's gaseous envelope structured on a large scale? What changes are occurring there? The *Venus Monitoring Camera* from Katlenburg-Lindau provides the answers. Its photos of the southern hemisphere show three very distinct zones in the Venusian cloud cover. Insolation is strongest near the equator; this is where turbulent convection currents transport the dark UV absorber from lower layers of the atmosphere upward. The images of these latitudes are thus dominated by dark markings in the UV.

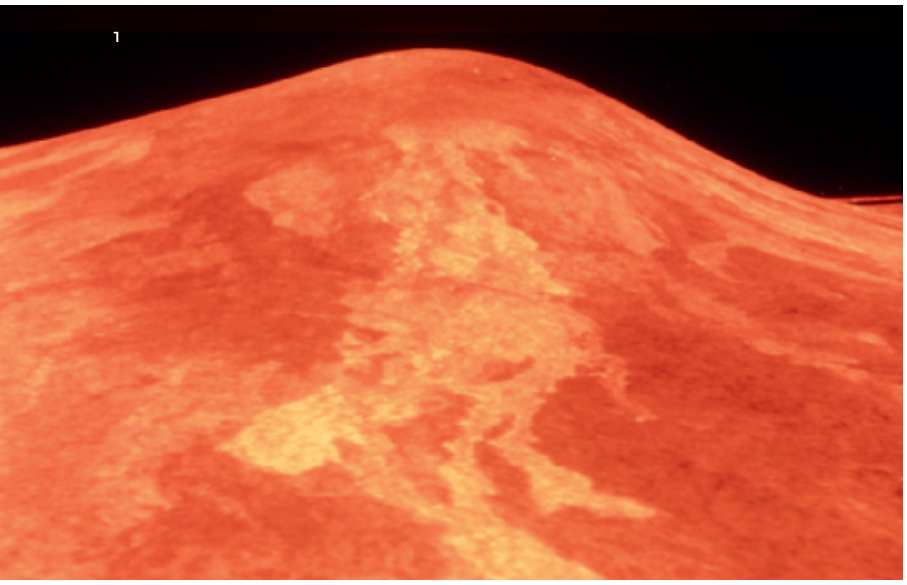
CLOUDS REFLECT A LARGE FRACTION OF SOLAR RADIATION

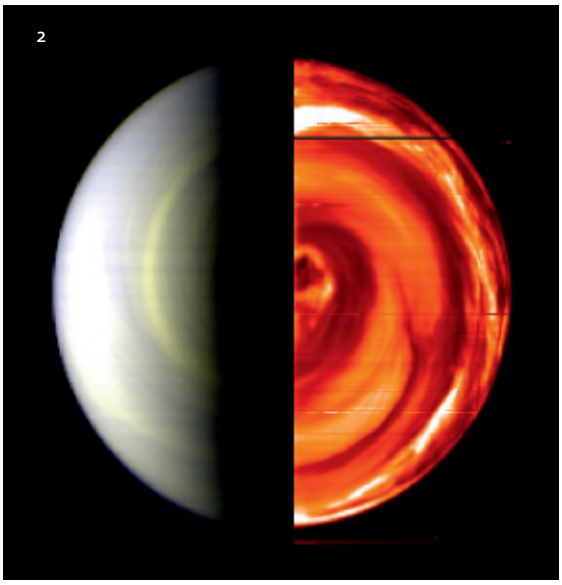
Things are different further south, beyond 40 degrees south latitude. There, the UV "eyes" of *Venus Express* see elongated, streaky cloud formations that suggest a more ordered, more laminar atmospheric current. They turn into a ring of bright, almost unstructured clouds that encircle the entire planet between 50 and 70 degrees south latitude. Aerosols presumably reflect a large fraction of the sunlight here before it reaches the UV absorber. This zone can be visualized as a stream of relatively cool Venusian air that circles the polar area.

The polar region itself has been offering the researchers an impressive spectacle since the beginning of the mission. A huge vortex of clouds rages there that rotates around the south pole in two and a half days and was discovered by the predecessors of *Venus Express*. Never before have scientists been able to study it in so much detail. Sometimes it resembles a hurricane on Earth. Sometimes it seems to have two centers, so that earlier Venus researchers had nicknamed it a "polar dipole." "Within a short time, the eye of the hurricane changes its appearance to such an extent that it is sometimes no longer possible to make out a dipole," says Max Planck researcher Titov.

The large-scale structure of the gaseous envelope over the southern hemisphere is typical of the whole planet, because the atmosphere in the north has a similar structure. The special orbit of the satellite makes the northern hemisphere suitable for detailed studies. For example, Katlenburg's camera was able to take pictures of wave trains – wave-like cloud structures that exist in a similar form on Earth. Little by little, even the mysterious UV absorber is now being forced to surrender its secret.

"By comparing the UV and infrared photos of such clouds, we were able to confirm with our cameras several times that the unknown UV absorber is also slightly absorbent in the near infrared,"





Photos: Magellan Project/JPL/NASA (left), ESA/MPS

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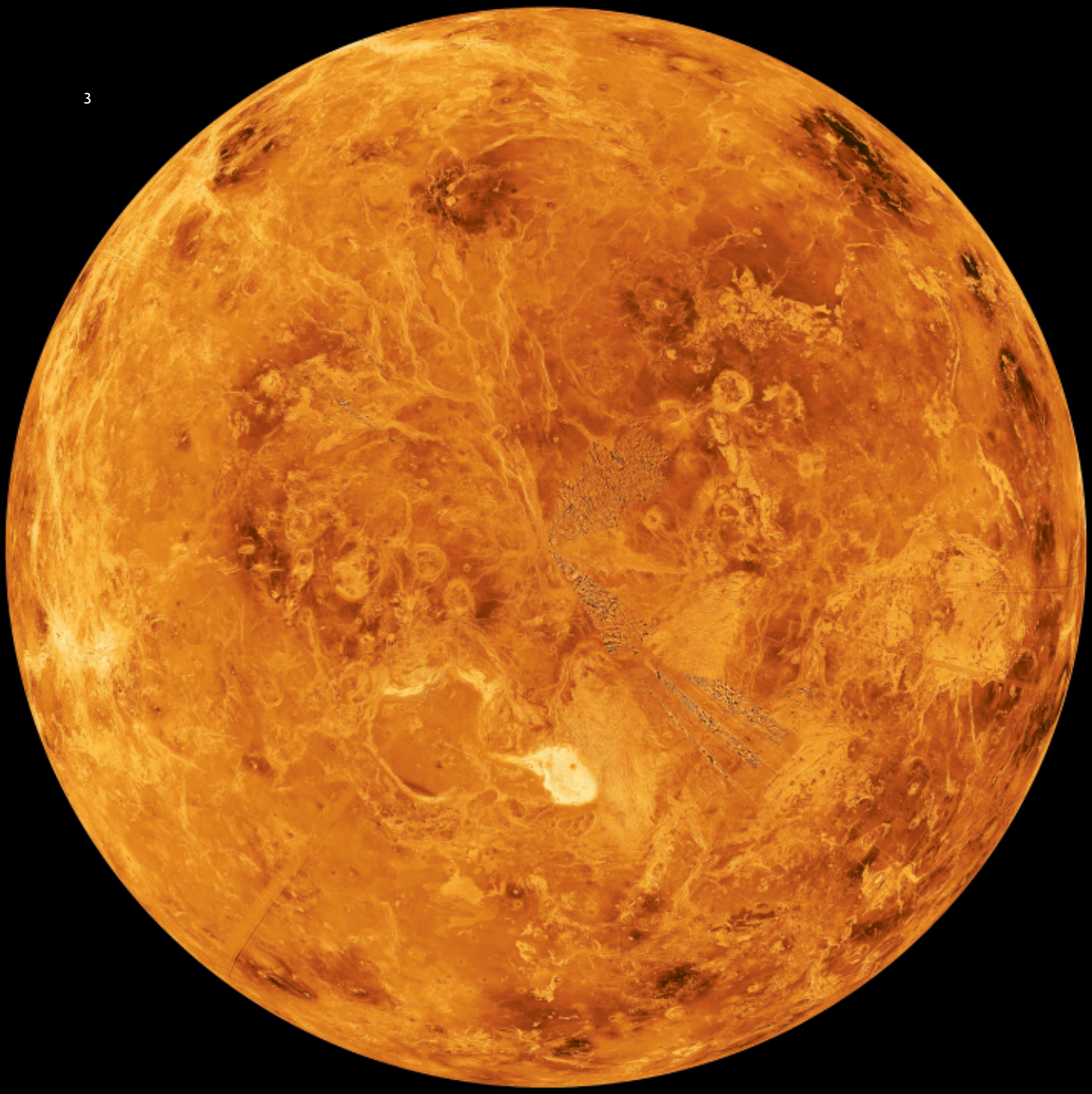
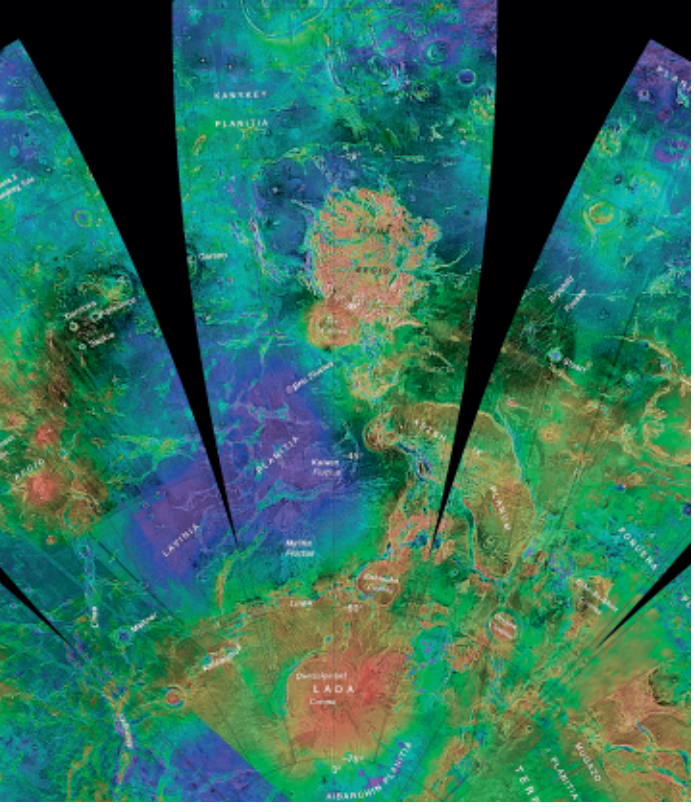


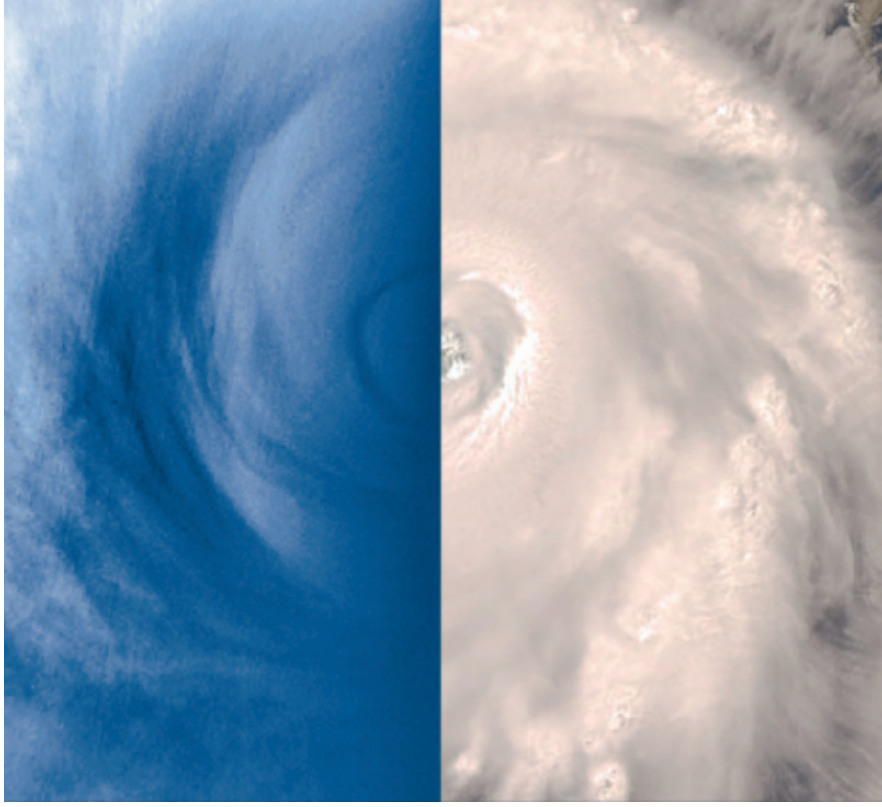
Photo: Magellan Project/JPL/NASA

1 The Venusian landscape was formed by volcanoes, such as the approximately 2,000-meter-high Sif Mons. Planetologists are now studying the geological history.

2 Two views of Venus's cloud-covered south pole. The left part of the image shows the gaseous envelope during the day in reflected sunlight, while the part on the right reveals it at night in thermal radiation. Both views show traces of a huge whirlwind.

3 Venus without its veil: Such views of the naked planetary globe are possible only with radar instruments.





left | Part of the southern hemisphere. The color scheme is based on altitude measurements: blue areas indicate the low-lying regions of Venus, green areas the central regions, and the highest areas are shown in ochre and brown to orange shades.

right | Sisters in turmoil: The image on the left shows a whirlwind on Venus, the one on the right, for comparison, Hurricane Frances on Earth. The latter was enlarged by about a factor of 5 to make both to scale.

explains Wojciech Markiewicz, the man in charge of the camera experiment at the Max Planck Institute for Solar System Research. His colleague Titov adds: "Although many substances are being discussed as the cause of the UV absorption, it may simply be a special modification of sulfur."

Although the approximately 25-kilometer-thick blanket of cloud obstructs the view to the surface in the visible wavelengths of the spectrum, the camera can still pick up details on the ground on the nightside. This happens as follows: Even on its nightside, the surface of Venus has a temperature of over 400°C, which means that the surface rocks emit heat radiation in the invisible infrared. Part of this radiation can get through the cloud cover in narrow spectral intervals called transparency windows. "Although the resolution of the photos is severely limited by multiple scattering in the clouds, we can nevertheless learn a lot about the surface," explains Markiewicz.

GLOBAL VOLCANIC ERUPTIONS POSE A MYSTERY

These photographic mosaics composed of more than 1,000 individual images show the temperature variations in Venus's landscapes. Just like on Earth, the valleys are warmer than the mountains, which rise to heights of up to 12 kilometers. The temperatures on a 5-kilometer summit are 40 degrees below those in the plain, for example. The planetologists also want to use such studies to learn more about the minerals in Venus's crust. According to conventional theories, the surface was created by planet-wide volcanic eruptions. This mysterious global catastrophe ravaged Venus some 500 to 600 million years ago.

The Magellan probe, which charted around 98 percent of Venus's surface, discovered large-scale volcanism back in the 1990s. The researchers counted about 1,000 volcanoes on its radar images. If Venus's volcanoes are still belching out fire, the *VMC* camera and the Visible and Infrared Thermal Imaging Spectrometer *(VIRTIS)* will be able to find them. The search continues.

But back to the sky above Venus, the real subject of the research mission. The planetologists use photos of individual cloud formations taken by *VMC* and *VIRTIS* to measure wind conditions in the stormy atmosphere. Movements occurring at different altitudes of the multilayered cloud system can thus be detected in the different wavelengths. This made it possible to carry out the first comprehensive 3D studies of Venus's storms: at an altitude of 66 kilometers, the clouds race at up to 370

Photos: NASA/JPL/DLR (left), Sanjay Limaye (right)

kilometers per hour, or as much as three times faster than hurricanes on Earth. Lower down, between 45 and 47 kilometers above the surface, speeds of 210 kilometers per hour can still be measured.

The researchers want to use such studies to find out what drives the "super-rotation" of the Venusian atmosphere. This rapid movement causes the higher gaseous envelope to circle the entire planet in just four Earth days. It moves in the same direction as Venus itself rotates. A Venusian day, on the other hand, is unusually long: the unequal sister planet takes 243 Earth days to rotate about its own axis – nearly 19 Earth days longer than it takes to complete an orbit of the Sun. A Venusian day thus lasts longer than a Venusian year.

The snail's pace of Venus's rotation about its own axis is probably one of the reasons for another important difference between this planet and the Earth: Venus has no global magnetic field. This fact probably also influenced the history of its climate, in particular the fate of the water, which the young Venus received as a dowry at the time of planet formation in the same way as Earth and Mars. Nor, incidentally, are there any plate tectonics on Venus.

In contrast to these two terrestrial planets, Venus is now extremely dry. Although water is present as a trace gas in the Venusian atmosphere, it makes up only 30 ppm (parts per million). If all of the water currently present on Venus were to collect on the ground and spread across the surface, the resulting "ocean" would be a mere three centimeters deep. The comparison value for Earth is nearly three kilometers.

An indication of Venus's wetter younger years was already provided by the American *Pioneer-Venus* probe, which reached its destination three decades ago. Its mass spectrometer investigated the isotopes of hydrogen in the droplets of the acidic Venusian clouds. In addition to the normal hydrogen (chemical symbol: H), *Pioneer* also measured the concentration of deuterium (D), known as heavy hydrogen. Deuterium accounts for only 0.015 percent of the hydrogen fixed in the water of Earth's oceans.

However, the measurements of *Pioneer-Venus* showed that the ratio of D to H on Venus is shifted by about a factor of 120 toward deuterium. This is because, since its formation, Venus has disproportionately lost the lighter H atoms into space. The heavier deuterium preferentially remained trapped in the gravitational field – a gradual enrichment in favor of this isotope. The D surplus, which *Venus Express* confirmed, thus points to a higher quantity of water when Venus was young.

ULTRAVIOLET LIGHT RAGES IN THE UPPER ATMOSPHERE

The loss of atmospheric gases continues to this day. With the *ASPERA* instrument (Analyzer of Space Plasma and Energetic Atoms), *Venus Express* has been able to prove the loss of hydrogen and oxygen, two H atoms being lost for every O atom – the same ratio as in the water molecule. Markus Fränz, who analyzes the *ASPERA* data at the institute in Katlenburg, does not believe in a coincidence: "Physical models explain that H_2O is broken up and ionized in the upper atmosphere by ultraviolet sunlight. The H ions and O ions can escape into space. This loss occurs primarily on the nightside of the planet."

Escaping H ions have since been measured on the dayside, as well. The researchers still have to discover which processes in the past and present have been driving the atoms out of the planets' gaseous envelopes. The main suspect is the solar wind, a stream of charged particles that are emitted by the Sun and that can accelerate atoms and ions so strongly that they leave the gravitational field. Fränz says: "At the moment, the Sun's activity is at its low point, and this also applies to the solar wind. But both change in an 11-year cycle. We want to study the erosion of the atmosphere in the coming years as the Sun's activity increases."

It is still too early to give certain answers to the key questions in the research into Venus. Nevertheless, Dmitriy Titov risks a provisional answer: Venus is not as mysterious as it appeared in the early years of planetary research. "In the beginning, it was similar to Earth. But its stock of carbon was not bound in carbonaceous rock by the action of the oceans, as it was on Earth. The carbon remained in the atmosphere as CO_2. This set in motion a self-amplifying greenhouse effect."

In the rising heat, all the water evaporated and was lost in space. Similar processes are also known on Earth, but on Venus they have amplified to a bizarre level. Corroborating this idea with long-term measurements is the task for the coming years – a great deal of work for *Venus Express* and its successor probes, which are already in the planning stages. ◂

GLOSSARY

Isotope
Atoms whose nuclei have the same number of protons (and therefore identical nuclear charges) but a different number of neutrons.

Plate tectonics
The visible expression of the Earth's plate tectonics is the movement of the lithospheric plates, commonly referred to as continental drift. Plate tectonics causes the formation of folded mountains and such phenomena as volcanism and earthquakes.

Greenhouse effect
Energy-rich UV and visible radiation from the Sun passes through a planet's atmosphere while long-wavelength heat radiation from the lower atmosphere, which is supposed to cool it, remains trapped due to the presence of absorbing gases and clouds. On Earth, it is primarily water vapor and clouds in the atmosphere that prevent the heat from escaping into space, resulting in a surface temperature increase by around 40 degrees Celsius. On Venus, the greenhouse effect is much stronger.

Witnesses
to Local Cosmic History

They have long been living in the shadows of our solar system: the asteroids and comets. They are small and dim, making them difficult to observe – but they can tell us many exciting stories about the formation of the solar system. Astronomers from the **Max Planck Institute for Solar System Research** in Katlenburg-Lindau are reconstructing this cosmic history.

TEXT **THOMAS BÜHRKE**

In spring 1997, the brightly shining Hale-Bopp appeared like a star in the sky. Comets fascinate researchers and laypersons alike.

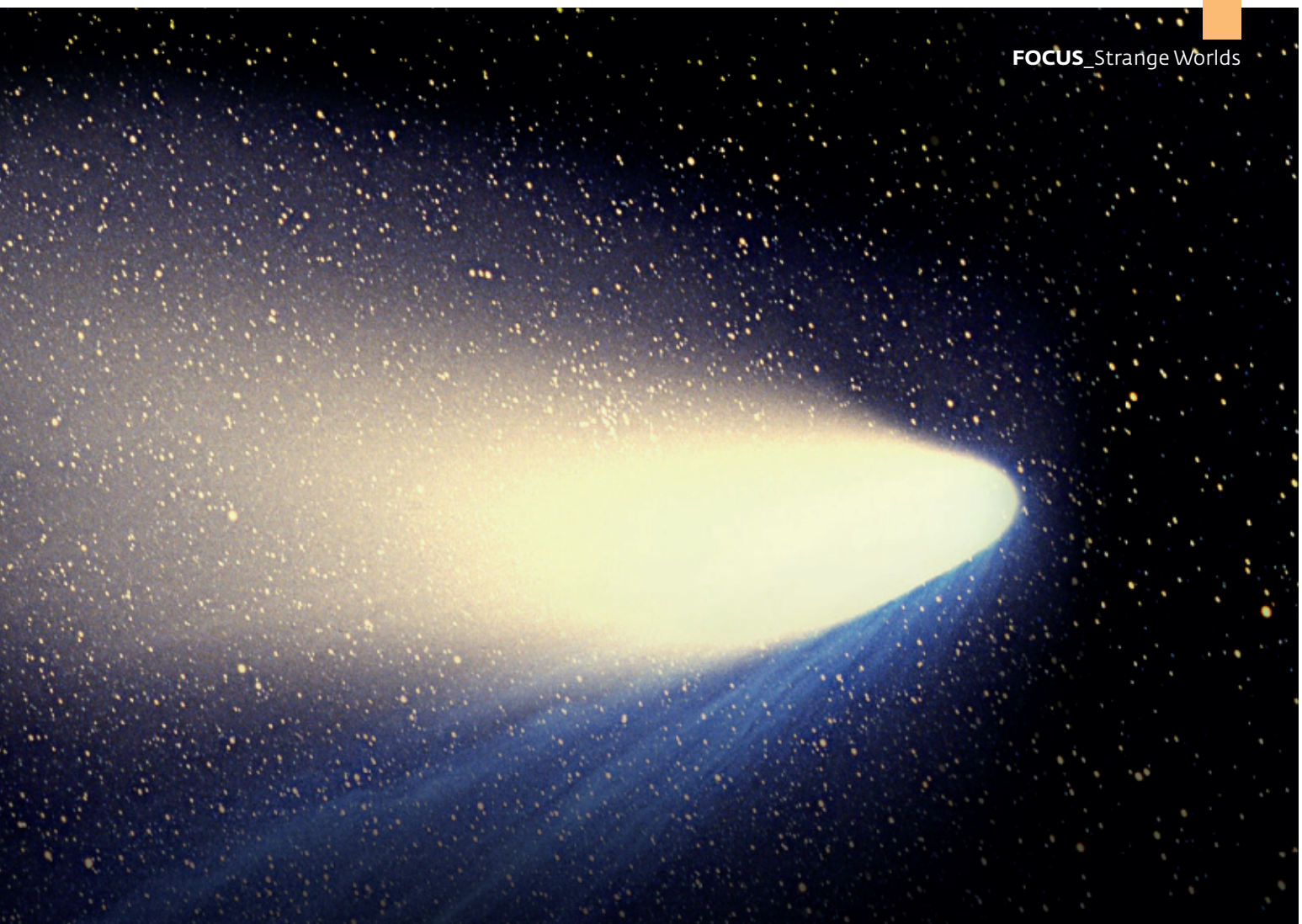


Photo: Linzer Astronomische Gemeinschaft – Erich Kolmhofer, Herbert Raab

The solar system is ordered like an ancient regime: in the center is the Sun King around whom everything revolves. The terrestrial planets Mercury, Venus, Earth and Mars orbit closest to the Sun, just like the royal court. Much further away, like the landed gentry, the gas giants Jupiter, Saturn, Uranus and Neptune live out their existence.

In terms of numbers, however, the asteroids and comets make up the bulk of the solar system. Just like the simple folk in historiography, they were long neglected by astronomers. Unjustly so, because these small bodies can reveal a lot about why our solar system became what it is today. Astronomers from the Max Planck Institute for Solar System Research persuade them to reveal these secrets with telescopes, simulations and space probes that they send to the celestial bodies.

Most asteroids, more than a million with diameters of one kilometer or more, orbit the Sun in the main belt between Mars and Jupiter. They are between 2.0 and 3.3 astronomical units away from our star, one astronomical unit (AU) being the distance from the Sun to the Earth. More objects made of ice and rock lead their lives in the Kuiper Belt beyond Neptune. Pluto has been their second largest representative since the International Astronomical Union expelled it from the planetary nobility three years ago for its lack of size, demoting it to the rank of dwarf planet. The Kuiper Belt extends over a distance of between 30 and 50 astronomical units.

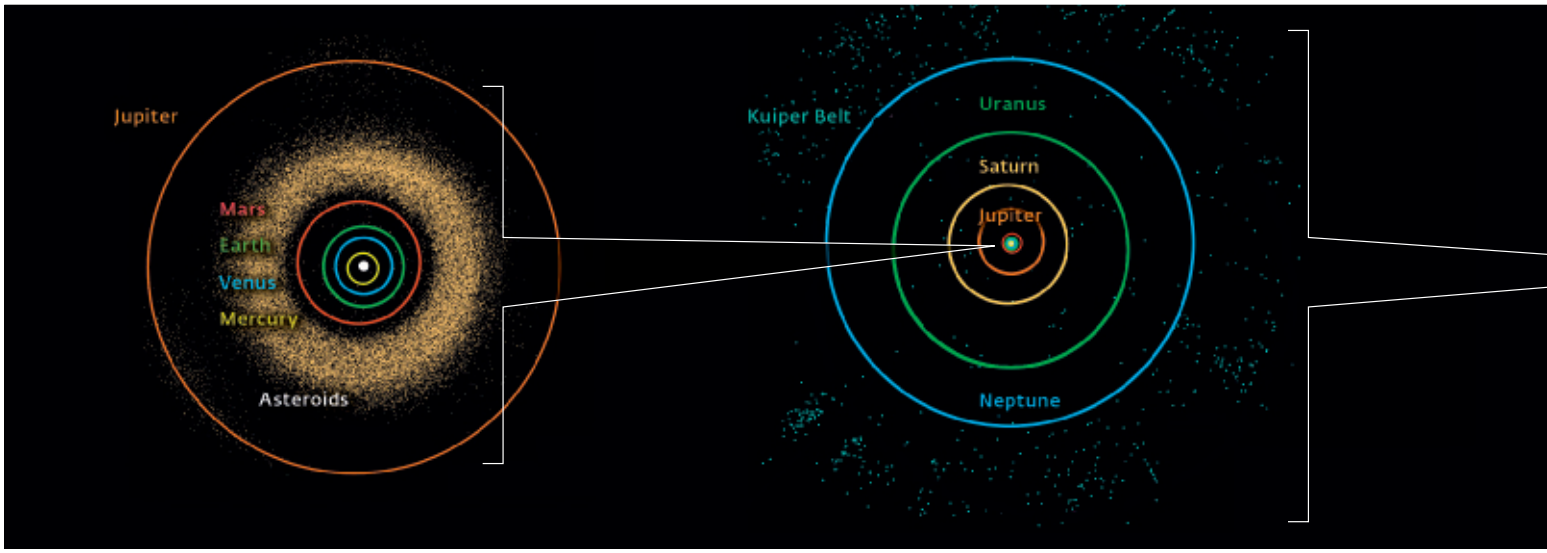
BUILDER'S RUBBLE FROM THE EARLY DAYS OF THE SOLAR SYSTEM

Astronomers estimate that at least 70,000 Kuiper belt objects with diameters exceeding one hundred kilometers buzz around the Sun, more than 1,300 of them having been discovered within the last two decades or so. They are the building material left over from the early days of the solar system, remains that never accreted into a large planet.

However, in no way does this mean that the edge of the solar system has been reached. Way out there, up to distances of tens of thousands of astronomical units, where no telescope can detect them, other ice-cold bodies trace out their orbits in the Oort cloud. Long-period comets, which appear in the inner solar system only once every few thousand years, originate from this reservoir.

Short-period comets, which appear in the sky at intervals of about 200 years or less, were once part of the Kuiper Belt. If one of them is ejected from this region by the gravitational effect of a planet, it approaches the Sun in an elliptical orbit. The constantly rising temperature causes these bodies to lose more and more gas and dust and to appear in the night sky as comets.

The journey of these asteroids and comets is not completely without danger. Although most bodies have been orbiting the Sun in the cosmic order for billions of years, they can still collide with a planet, even Earth. Even back in



the 17th century, Isaac Newton wondered whether the system was really stable. He could not prove it and thought divine intervention would be necessary if the cosmic clockwork were ever to stop keeping time.

Even if Newton probably drew the wrong conclusions, his doubts regarding the lasting nature of the solar system were not that far off track. In the distant future, it is unlikely that any planet will be ejected from its orbit by the gravitational effect of the other planets, but in recent years, there have been growing indications that the solar system has not had its present structure since the very beginning. "There are good reasons for assuming that the large planets initially shifted over large distances before taking up their present orbits," says Hermann Böhnhardt from the Max Planck Institute for Solar System Research in Katlenburg-Lindau.

This would suggest that our solar system shook itself into shape in its wild adolescence, so to speak, before it came to rest. But how is it possible to determine this today? This is where the cosmic vagabonds can help: "In contrast to most of the planets, many asteroids and almost all comet nuclei have hardly changed since their formation. They still contain information about how the solar system was formed," says Böhnhardt. The scientist has been studying these celestial bodies for more than 25 years, trying to coax their history out of them.

COLORS AND ORBITS ARE CONNECTED

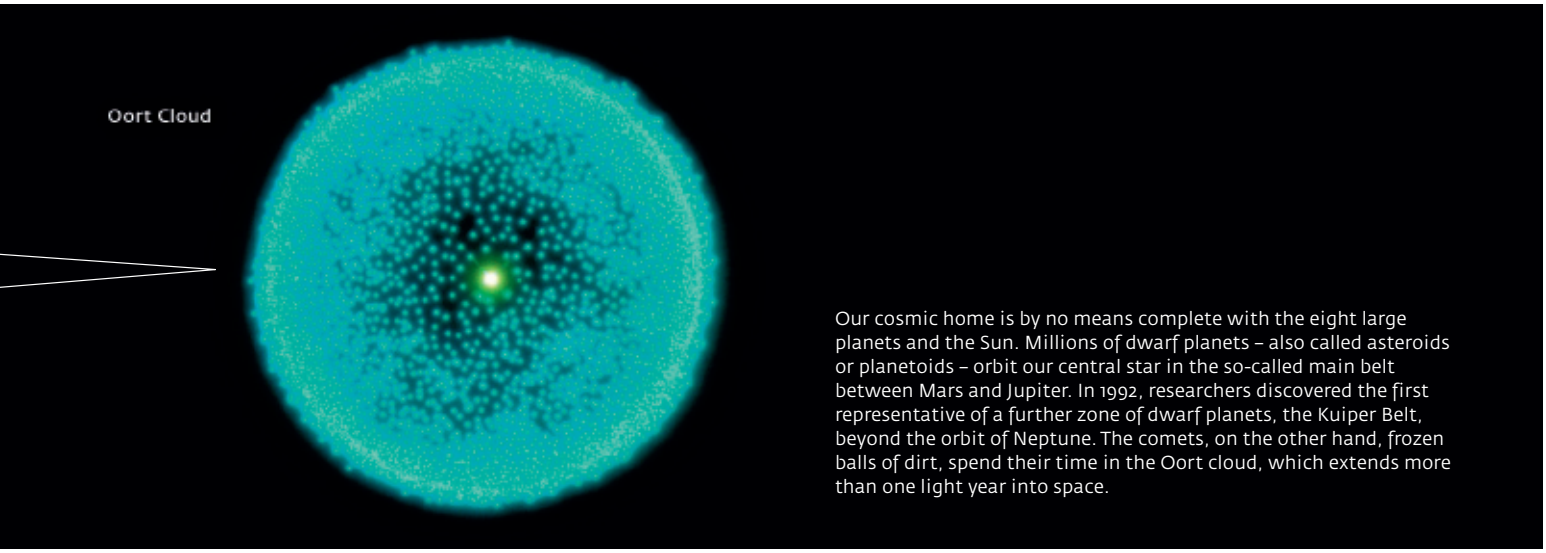
Astronomers initially assumed that the objects in the Kuiper Belt were formed where they can still be found today. If this were so, they should all have roughly the same characteristics and similar surface colors. This is not the case. "Surprisingly, they exhibit a wide variety of colors, ranging from reddish to grayish-white," explains Böhnhardt.

When he examined about 170 Kuiper belt objects in detail with colleagues from France and the US last year, he discovered a relationship between the colors and the orbits. The researchers now distinguish several categories of Kuiper belt objects. There are the "classical" bodies, for example, which move in a region between 40 and 50 astronomical units from the Sun in almost circular orbits. The study showed that these objects appear predominantly reddish. A different group, the so-called scattered Kuiper belt objects, move in elliptical orbits and appear predominantly white. How can this be explained?

At temperatures below minus 200 degrees Celsius, the surfaces of the Kuiper belt objects are mainly covered with water and methane ice, which is subjected to constant bombardment of energetic particles and UV radiation from space. In the course of billions of years, methane changes into more

The focus is on the bits and pieces: Planetoids (left, the asteroid Ida) and comets (right, the crumbling Schwassmann-Wachmann 3) contain information on the early history of the planetary system.

Photos: NASA Jet Propulsion Laboratory, (NASA-JPL) (top, 2); Galileo Project, JPL, NASA (bottom left), NASA, ESA, H. Weaver (APL/JHU), M. Mutchler and Z. Levay (STScI) (bottom right)



Our cosmic home is by no means complete with the eight large planets and the Sun. Millions of dwarf planets – also called asteroids or planetoids – orbit our central star in the so-called main belt between Mars and Jupiter. In 1992, researchers discovered the first representative of a further zone of dwarf planets, the Kuiper Belt, beyond the orbit of Neptune. The comets, on the other hand, frozen balls of dirt, spend their time in the Oort cloud, which extends more than one light year into space.

complex organic compounds, such as tholins, which give the celestial bodies their reddish-brown color. This could explain the color of the classical Kuiper belt objects, but why are the scattered bodies more whitish?

COSMIC COLLISIONS RELEASE ICE

These objects move in elliptical orbits, which increases their chances of colliding with each other. During those cosmic collisions, fresh, white ice is released from the inside and deposits on the surface. "Collisions certainly play an important role in the development of the Kuiper belt objects," says Böhnhardt, but whether they can explain all of the characteristics is still unclear. These small bodies can also consist of different materials, of course.

The reason why the Kuiper belt objects form several main groups with different orbital characteristics is also only partially understood as yet. Four of these families are presently forced into their orbits by the gravity of the large outer planets. For two further groups, the cause is probably to be found in a turbulent early phase of our cosmic home.

After the planets had formed in the young solar system, they moved around the Sun in a disk that also contained many small bodies of different sizes. As far back as 1984, Wing Ip and a colleague, who were then working at the Max Planck Institute for Solar System Research, discovered that the large planets with their immense gravity must have hurled the small bits and pieces to and fro in the solar system. But even the planets themselves did not remain completely unmoved. Depending on their constellation, they lost or gained energy in these processes and thus migrated in spiral orbits closer to the Sun or further away from it.

Theoreticians from the Nice Observatory worked through this basic idea four years ago in extensive computer simulations and made a sensational discovery. Jupiter may have moved closer to the Sun as a result of its interaction with the small bodies, whereas Saturn, Uranus and Neptune drifted further out. Neptune pulled a swarm of small bodies with it, which can now be found in specific orbits in the Kuiper Belt. The existence of another group can also be explained fairly well with this game of planetary billiards.

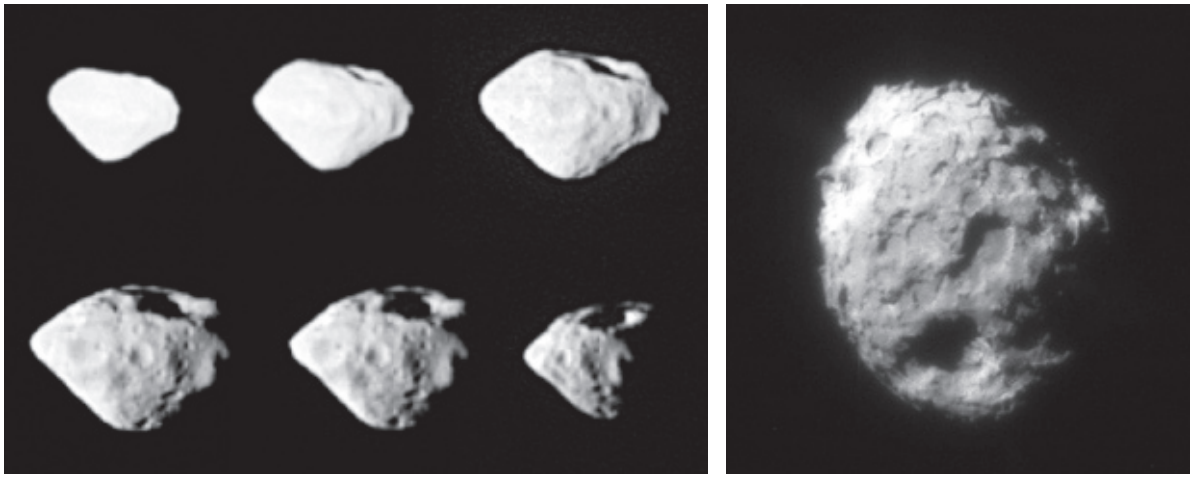
This Nice model also makes a further prediction. As the planets migrated, there was very probably a period when Saturn needed exactly twice as long as Jupiter to complete one orbit around the Sun. During this so-called 1:2 orbital resonance, the gravitational interaction between these two bodies reached a maximum, and the orbits then quickly deformed to become elliptical.

The planets crossed the circular orbits of the small bodies nearby on elliptical paths and these small bodies were now also increasingly catapulted toward the Sun, causing an increased bombardment of the inner planets, including the Earth and the Moon. This also made it possible to explain the so-called late heavy bombardment, in which the inner planets were hit by an especially large number of cosmic missiles about 700 million years after their formation.

KUIPER BELT OBJECTS – OBSERVED IN INFRARED LIGHT

The Nice model was thus able to elegantly explain several phenomena in the solar system at the same time. Future research will need to show whether it really happened like this. To this end, Hermann Böhnhardt in collaboration with Thomas Müller from the Max Planck Institute for Extraterrestrial Physics in Garching and further astronomers have initiated a program at the recently launched *Herschel* space observatory of the European Space Agency (ESA). It is the largest telescope ever stationed in space. The researchers want to use it to detect the characteris-

Photo: SPL – Agentur Focus



Space potatoes in all shapes and sizes: The sequence on the left shows different views of the Steins planetoid, taken during the rendezvous with the European scout *Rosetta*. On the right of the image is the nucleus of comet Wild 2, which the US space probe *Stardust* photographed from close up.

tics of as many Kuiper belt objects as possible in the infrared and have obtained close to 400 hours of observation time in which to do so.

INTERPLANETARY VAGABONDS AS WATER CARRIERS?

The results of the late heavy bombardment can still be seen on the surface of the Moon: the large dark maria testify to severe hits. But without question, severe impacts had already occurred before. Astronomers have thus long been discussing whether comets brought the water to Earth in this way. The question is also interesting because comets contain organic molecules. It is only recently that American researchers discovered the amino acid glycine in the dust of the comet Wild 2. Is it possible that the comets also brought seeds of life to our planet?

This hypothesis is as fascinating as it is daring, and it can indeed be tested, because all water is not the same. A water molecule consists of two hydrogen atoms and one oxygen atom. In addition to normal hydrogen with one proton in the nucleus, there are two further naturally occurring isotopes: deuterium and tritium. Apart from the proton, their nuclei contain one or two neutrons, respectively.

In "normal water" on Earth, there are 6,410 atoms of hydrogen to each atom of deuterium. In comets, scientists have so far been able to measure this ratio in only four cases: Halley's Comet, Hyakutake, and Hale-Bopp. These measurements showed that cometary water contains a significantly higher proportion of deuterium. However, the results were very imprecise. Last year, a team of astronomers, including Böhnhardt, succeeded in spectroscopically measuring deuterium in the Tuttle comet.

The scientists used the world's most powerful spectrograph at the *Very Large Telescope* of the European Southern Observatory (ESO) in Chile for this task. The result was unambiguous: The hydrogen-deuterium ratio was 2,445:1 and thus not even half as large as the ratio on Earth, which correlated well with the observations from the other three comets. In other words, deuterium seems to be significantly enriched in cometary water compared with the situation on Earth.

All the evidence thus currently points to the comets having brought only a small proportion of the water to Earth – if any at all. But this question has not yet been answered conclusively. "We must first clarify whether the isotope ratio is the same in all comets," says Hermann Böhnhardt, expressing his reservations.

So there is still a lot of research to be done on the comets and Kuiper belt objects. Observations with powerful telescopes are one possibility; flying there is the other. Since Europe's space probe *Giotto* investigated and took the first close-up photographs of a comet in 1986, only a few other space ships have flown to a comet. Among them, the American probe *Stardust* reached comet Wild 2, collecting dust from its tail and bringing it back to Earth in January 2006.

A PROJECTILE DRILLS INTO THE COMET'S CORE

The encounter between *Deep Impact* and Tempel 1 was particularly spectacular because the space ship fired a 360-kilogram projectile into the comet's nucleus, which measures about three kilometers across. When it struck on July 4, 2005, there was a violent explosion that ejected material from the surface. This provided the first opportunity to study matter from the inside of a comet.

Since the mother probe itself had only limited measuring capabilities, Karen Meech from the University of Hawaii – a *Deep Impact* scientist at the

Photos: ESA/Stardust Team, JPL, NASA

Photo: Stefan Seip

The question as to whether the comets brought the water to Earth is still unanswered. What is certain is that there were very many collisions with comets in the early history of our planet – the terrestrial sky must frequently have played host to magnificent cosmic vagabonds such as the Machholz comet, which passed in front of the open Pleiades cluster (top) in winter 2005.

Point landing in a strange world: This is how it will look when the *Philae* probe makes a soft landing on comet Churyumov-Gerasimenko in 2014. It will be the first time scientists are able to study such a celestial body at close range.

time – initiated a worldwide observation campaign for the event. Telescopes in nearly one hundred observatories were pointed at the comet to study the light from the ejected matter. "On July 4, all the telescopes at ESO were kept available for this task," remembers Böhnhardt.

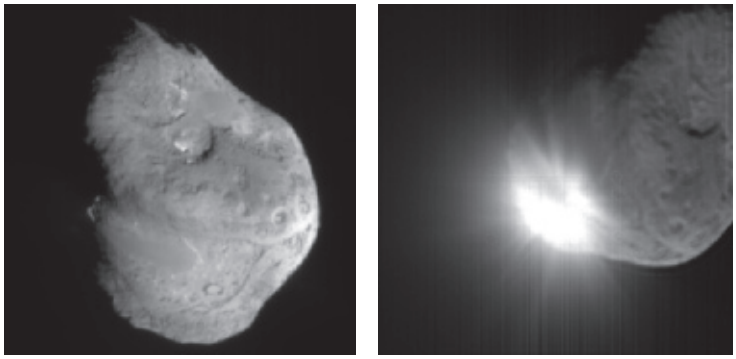
One result particularly surprised the researcher: crystalline silicates were detected in the dust that had been whirled up. This was surprising because these minerals form only at high temperatures. The assumption is that comets formed a long way from the Sun, where the temperatures are significantly below freezing. Experience has shown that only amorphous, or irregularly formed, silicates exist in this cool region. The crystals could not have been formed by the impact of the projectile from *Deep Impact*. "Its energy was much too low for that," says Böhnhardt. So how did they get into the comet?

Most astronomers now assume that, in the solar nebula, hot material from somewhere near the Sun must have been transported into the outer regions, where it was then incorporated into the comet. Astronomers at the Max Planck Institute for Astronomy in Heidelberg confirmed this hypothesis a few months ago. They detected crystalline silicates in the outer regions of the dust disk of a distant young star called EX Lupi. EX Lupi is now at a stage that our Sun went through more than four billion years ago. The conditions should thus be comparable. What is not yet known, however, is how the crystals were transported to the outer regions of the disk.

COMA AND TAIL IN ITS SIGHTS

The next highlight of comet research will be achieved by ESA. If everything goes according to plan, the *Rosetta* space probe will reach comet Churyumov-Gerasimenko in 2014 and turn in

Graphics: ESA



Deep Impact – not fiction, but science: Not only the name of a Hollywood film, but also a US probe that flew to comet Tempel 1 (left) in July 2005 and fired a 372-kilogram projectile at its nucleus. A cloud of dust and gas was ejected into space on impact (right). The energy released in the collision was the equivalent of 4.5 tons of TNT – but the comet remained in one piece.

to orbit around its nucleus. After several months, the mother probe will then shed the 100-kilogram landing probe *Philae*, which will softly land on the comet's nucleus, which measures only a few kilometers across. This will be the first time it will be possible to thoroughly investigate a comet in situ.

There is still some time to go until then, but for Hermann Böhnhardt and his colleagues, the preparations have already begun. They are using large telescopes to study the comet's activity in order to find out the distance from the Sun at which the frozen gases begin to sublime, for example, and form a coma and a tail.

Rosetta itself has already passed one test with flying colors. In September last year, it flew past asteroid Steins at a distance of just 800 kilometers. Four and a half years after the launch, most of the onboard instruments were switched on for the first time to test them for scientific purposes.

Unfortunately, the tele-camera of the *OSIRIS* camera system switched to safety mode nine minutes before the closest approach, with the result that pictures were sent to Earth from only the wide-angle camera. They show a body some 5 kilometers in diameter, covered with deep craters. "But the tele-camera is just fine," as Horst Uwe Keller assures us. He is the man who headed the development of *OSIRIS* at the Max Planck Institute for Solar System Research. All of the comet researchers are now eagerly awaiting *Rosetta's* arrival at Churyumov-Gerasimenko. And when *Philae* lands on the comet, the scientists from Katlenburg-Lindau will be excited too. The *COSAC* instrument, which was developed under their overall control, will look for organic matter in the cold lump of ice and rock. ◂

GLOSSARY

Asteroids
Bodies, also called dwarf planets or planetoids, that circle the Sun in more or less elliptical orbits. The smallest asteroids resemble a small stone, and the largest is Pallas with a diameter of 546 kilometers. Around half a million asteroids are known at present. Some cross the Earth's orbit and could collide with our planet. If a small asteroid enters the atmosphere, it begins to glow like a meteor. What remains and reaches Earth is called a meteorite.

Comets
Bodies of ice and rock that move in strongly elliptical orbits around the Sun. If a comet's nucleus comes close to the Sun, it releases gas. This initially collects in a coma about the body but is then drawn out by the particle wind and the radiation of the Sun to form the characteristic tail.

Kuiper Belt
A ring-shaped zone of asteroids beyond the orbit of Neptune at a distance of between 30 and 50 astronomical units. The first Kuiper belt object was discovered in 1992.

Oort cloud
A region shaped like a spherical shell in which asteroids encircle the solar system at a distance of between 300 and 60,000 astronomical units (50,000 astronomical units correspond to one light year). This is where long-period comets originate.

Sublimation
The direct transition from the solid to the gaseous state. In comets, for example, slightly volatile substances sublime on the Sunward side of the nucleus and carry along dust particles embedded in the ice. This forms a coma and a tail.

Photos: NASA/JPL-Caltech/UMD

The Genetic Diversity of Rice

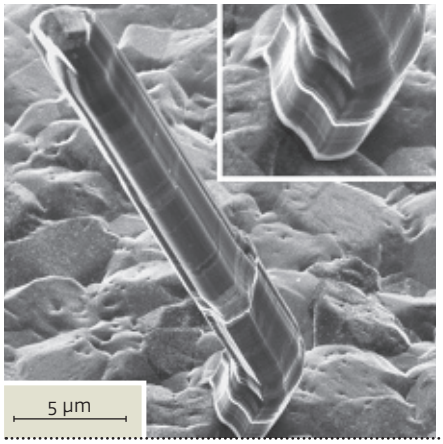
A map showing which genetic changes result in specific characteristics might make breeding new varieties more straightforward

It might be easier to breed new varieties of rice in the future. A database now shows breeders which genetic modifications give rise to specific characteristics in rice plants. An international team of researchers, including scientists from the Max Planck Institute for Developmental Biology and the Max Planck Society's Friedrich Miescher Laboratory in Tübingen, found 160,000 differences in the genes of 20 rice varieties and used the information to create a variation map. Many of the changes affect metabolic processes such as production of amylose, a sugar, or of cellulose. The variation map could also help identify which genes are important for breeding rice varieties that give better yields or are more nutritious or more resistant to drought. It also shows the scientists which varieties were used to breed the rice plants in use today. It appears that the first rice breeders crossed rice plants from India and Africa with other varieties in order to make them more resistant to drought and to high salt levels in the soil.
(PNAS, July 13, 2009)

Genetic variation in rice can explain both the visible differences between the different varieties and their preference for certain environmental conditions – for example, whether they thrive in the lowlands or at higher altitudes.

Getting to the Root of Dangerous Hairs

A short circuit can be quite hairy. Satellites have failed, a NASA computer center was repeatedly paralyzed, and the US public health authority recalled thousands of pacemakers – all because tin hairs sprouting from the solder and plating of copper components caused the devices to short-circuit. A team of scientists from the Max Planck Institute for Metals Research working with Robert Bosch GmbH measured in detail the forces that trigger this metallic hair growth. According to their findings, the pressure of the tin atoms at the root of a hair, which is called a whisker in technical jargon, must be lower than the pressure further away. Furthermore, this difference in pressure must exist in every direction throughout the layer of tin. The result is similar to what happens in a tube of toothpaste: squeeze the sides and the toothpaste comes out the top. The pressure builds up because an intermetallic compound forms at the interface between the tin and the copper and forces its way into the layer of tin. The tin whiskers can be up to several millimeters in length and just a few micrometers in diameter. An accurate understanding of how they grow could help prevent them.
(Applied Physics Letters, June 2009)



A highly magnified metal hair: This image from an ion beam microscope shows the form in which a tin whisker grows.

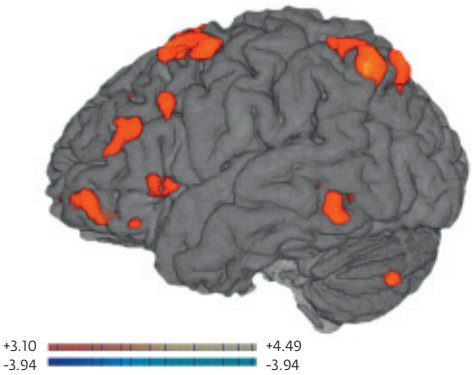
Photo: MPI for Metals Research (bottom), design: K. McNally, photo: Chrisanton Quintana (International Rice Research Institute, IRRI) (top)

Do You Speak Formula?

Mathematical syntax is processed in specific areas of the brain

Like language, mathematics has grammar rules. However, our brain makes use of significantly more areas to analyze mathematical formulas than it does to understand the natural language that we speak. In order to process mathematical grammar, or syntax to be more precise, the brain also activates areas that are involved in solving brain teasers. Scientists at the Max Planck Institute for Human Cognitive and Brain Sciences use these findings to explain why the weather forecast makes more sense to us than the statement "If a is less than b and b is less than c, then a is less than c." The researchers asked their subjects to read formulas without any numbers in order to distinguish between the processing of mathematical syntax and the processing of number values.

Nevertheless, the functional magnetic resonance tomograph revealed activity in the intraparietal sulcus (IPS), where numerical awareness is located. Other areas that work on the analysis of formulas are located around the Broca's area, the actual language processing center, and the left frontal cerebral cortex.



The grammar of mathematics makes the brain work very hard. The image shows which areas of the brain are active when a correct formula is being processed. These areas include those for numerical awareness and sections around the language center.

Generosity Pays

Generosity could help the music industry escape the plight to which it has been brought by illegal music downloads. The online music label Magnatune is setting an example. It allows its customers free and unlimited access to music streaming before they make a purchase so that they can get an idea of how the music sounds before they buy an album. Researchers at the Max Planck Institute for Economics think that this generosity is the reason for consumers' subsequent generous spending. They set a price between $5 and $18 for an album themselves and pay on average USD 8.20, or 64 percent more than the minimum required and also more than the USD 8.00 Magnatune recommends. If people were only out to maximize their profits, as economists have long suspected, they would offer the bare minimum. Various tests show that the amount paid depends very much on the fixed price range and on the recommended purchase price.

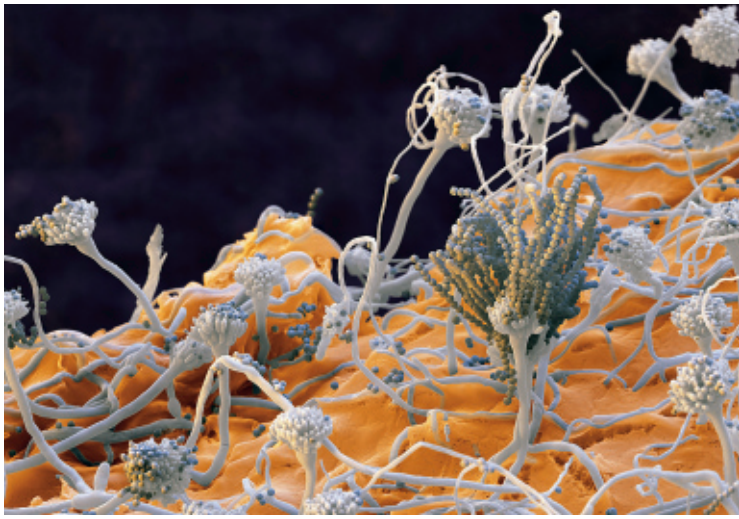
(Journal of Economic Behavior & Organization, August 2009)

Photo: BASF (bottom), graphic: MPI for Human Cognitive and Brain Sciences (top)

A Sky Full of Fungi

There are more types of fungal spores floating in the air than previously thought. Scientists at the Max Planck Institute for Chemistry have used DNA analysis to identify several hundred types of fungi. One cubic meter of air contains between 1,000 and 10,000 fungal spores. In order to find out what type they are, the researchers filtered fine and coarse dust from the air and examined its genetic content. Using various types of genetic tackle, they fished the genes of different types of fungi out of the gene soup. The researchers are mainly interested in fungal spores because they act as biological aerosol particles and play a role in the climate. The spores can function as condensation and crystal nuclei on which water precipitates or freezes. The spores thus contribute to the creation of clouds, fog and precipitation. Fungal spores also indicate how climate change is affecting ecosystems. Finally, they trigger allergies and cause disease in humans, animals and plants. Knowing which fungi are present in the air might help combat these ill effects.

(PNAS, July 13, 2009)

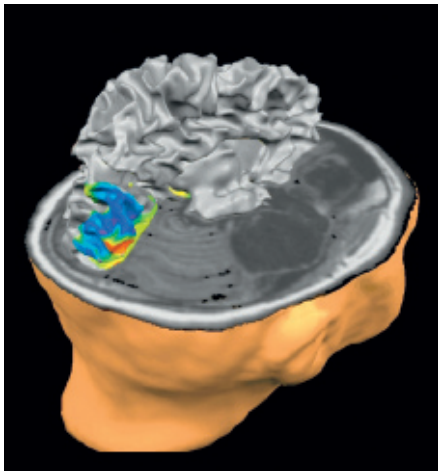


A source of fungal spores: Small and spherical, they sit on the surface of the mold fungus *Emericella nidulans*, which spreads by releasing spores into the air.

Full Sight with One Brain Hemisphere

One brain hemisphere is able to process information from both eyes

The neurologists must have doubted their MRI scanner when they examined the girl they presented to the world as AH: The right hemisphere of her brain was missing. The fact that AH suffered only slightly restricted movement and minor convulsions was thus surprising. Max Planck scientists have now established that even her eyesight is almost as good as that of a person with a complete brain. This is astonishing because, normally, the left hemisphere of the brain processes the right-hand field of view, and the right hemisphere handles the left-hand field of view. "A case where half of someone's brain can represent the whole field of vision has never been described before," says Wolf Singer, Director at the Max Planck Institute for Brain Research. The researchers suspect that, due to a developmental failure, the right hemisphere stopped growing about a month after fertilization. It appears that, at that point, the brain is able to compensate for such massive damage itself. One reason for this is that all the nerve fibers from the left eye can still be diverted to the left hemisphere.



The patient presented by neurologists as AH has only half a brain. Her eyesight is almost normal because, exceptionally, the single hemisphere processes information from both eyes.

Bats Can See Color

Even notorious night flyers find the ability to see color helpful. Researchers at the Max Planck Institute for Brain Research and the University of Oldenburg have found cone cells – sensory cells with pigment for color vision – in the retina of two types of bats native to Central and South America. As cone cells are useful only in daylight, they make up no more than 4% of the visual cells. The remaining visual cells are rods, which are sensitive to light and dark. They allow nocturnal creatures to see well – although only in black and white – even when light conditions are poor. The scientists have found two different types of cone cells: L-cones, which respond to yellow-green light, and S-cones, which are sensitive to ultraviolet light. The UV-sensitive visual cells could help these bats find food, as they collect pollen and nectar from flowers, and many flowers reflect UV light. The color-sensitive cells also help the creatures orient themselves in the twilight and see birds of prey, at least at distances of more than ten meters. They completely rely on echo location over shorter distances.
(PLoS One, July 28, 2009)

A Butterfly with Baggage

Test flight for science: Researchers plan to study butterfly migration using the Monarch butterfly.

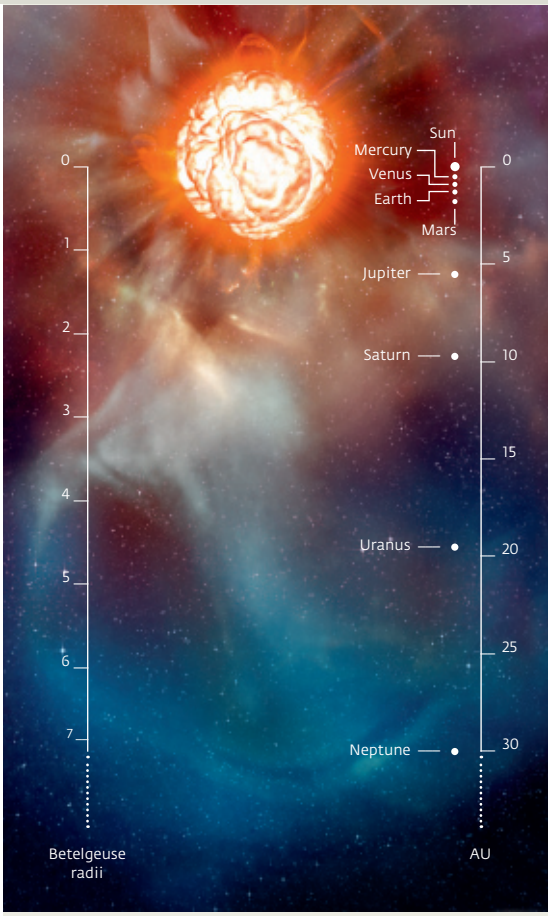
Some Monarch butterflies will soon be loaded with ballast as they fly thousands of miles from Mexico to Canada. For the first time, researchers from the Max Planck Institute for Ornithology and Kansas University attached radio transmitters to the abdomens of butterflies, fed them well and then sent them on their way as part of an experiment. Although the transmitters are tiny, they weigh half as much as the butterflies themselves. Their purpose is to reveal more about Monarch butterfly migration. In two or three generations, the creatures move north from their winter quarters in Mexico's Sierra Nevada. Some of them reach the Great Lakes in Canada. The next generation then manages the 3,600 miles back to Mexico in the late fall. The researchers want to compare the data on butterfly migration with that of whales, birds and bats. They may then be able to derive laws with which migration phenomena, such as that of the migratory locust, can be predicted.

Photo: Muckli, Naumer & Singer, 2009 National Academy of Sciences, USA (top); MPI for Ornithology, Radolfzell

A Powder to Prevent Energy Waste

Max Planck chemists use a simple method to convert methane to methanol, which might make it possible to access previously unusable natural gas

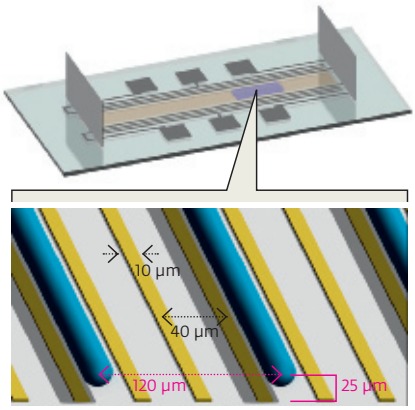
It might no longer be necessary to burn off natural gas. Scientists at the Max Planck Institute of Colloids and Interfaces have developed a catalyst that simply and efficiently converts methane, the main constituent of natural gas, into methanol. The catalyst is a powder consisting of a nitrogenous material, a covalent triazine-based framework (CTF), into which platinum atoms have been inserted. CTF is very porous and thus has a large surface area, giving the methane ample room to react. This is what makes the catalyst so efficient, and because it is a solid, it is also easy to handle. It could also be worthwhile to use it to convert methane to methanol where other chemical processes or even a pipeline are not economical. It might then no longer be necessary to burn off more gas during oil extraction worldwide than is consumed by Germany each year. The process could also be helpful in tapping unprofitable sources of natural gas. It is currently estimated that natural gas resources will last another 130 years; however, the reserves where extraction is economical will flow for no longer than the next 60 years or so. (Angewandte Chemie Int. Ed., in press)



Betelgeuse is a swirling giant. This artist's impression shows its enormous size in relation to the inner solar system.

Molecules in a Microtrap

The way Sam Meek and his colleagues manipulate molecules on a chip is reminiscent of the skills of a soccer player: in the same way as he intercepts a pass with a deft movement of his leg, holds the ball still and then shoots it into the back of the net, these researchers at the Fritz Haber Institute of the Max Planck Society use electric fields to slow down carbon monoxide molecules and then speed them up again to be picked up by a detector. All of this happens over a distance of just five centimeters. What is more, the molecules move approximately ten times faster than a ball with a powerful boot behind it. Using 1,240 gold electrodes, the physicists control how the electrical fields, which catch the molecules as they fly past, move the molecules over the chip. Their clever trick makes it easier to carry out experiments with gas molecules. Such experiments could bring new knowledge about chemical reactions in industry or in the atmosphere. Previously, this required very large and expensive pieces of equipment. (Science, June 26, 2009)



Sam Meek constructed the molecule trap on a chip (top). It consists of 1,240 gold electrodes, shown on the diagram (bottom) as yellow strips. Using six different voltages, Meek and his colleagues created cylindrical potential traps (blue) in which they catch molecules.

Graphic: Fritz Haber Institute of the MPS (bottom), photo: ESO/L. Calcada (top)

A Giant in Turmoil

It's a form of astronomical end-of-life care: an international team working with researchers from the Max Planck Institute for Radio Astronomy observed a dying giant star in better resolution than ever before. The astronomers used the Very Large Telescope Interferometer (VLTI) on Cerro Paranal in Chile to observe Betelgeuse, which is the bright orange star that sparkles at Orion's left shoulder. They found that the atmosphere of the star creates gas bubbles that move up and down at speeds of around 40,000 kilometers per hour. The bubbles explosively eject material and become as large in diameter as the orbit of Mars around the Sun. This makes the bubbles almost as large as Betelgeuse itself – which, if it occupied the same place as the Sun, would swallow up Mercury, Venus, Earth, Mars and very nearly Jupiter, too.
(Astronomy & Astrophysics 2009)

Gone with the Wind – A Volcanic Plume

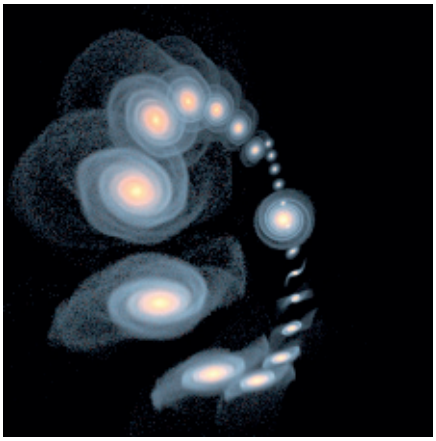
The jet stream drives gas and ash toward Europe at speeds of 540 kilometers per second

The monitoring flight was almost over and the *Leverkusen* was approaching Frankfurt airport when it snatched a few more air samples – and these were very special ones. The aircraft with the Caribic project's measurement container on board flew through the plume that the Kasatochi volcano had ejected the previous week. However, the researchers from the Max Planck Institute for Chemistry in Mainz did not discover this until later. The volcano is situated in the Aleutians, a chain of islands in Alaska. When it erupted, it sent 1.5 million tons of sulfur dioxide several kilometers into the air. The jet stream, a wind that blows at an altitude of more than ten kilometers, must have blown the cloud of gas and ash to Europe at speeds of 540 kilometers per hour. This was the only explanation that the chemists from Mainz could find for the concentration of sulfur, which was ten times higher than expected, and for the quantity of very fine dust particles, which was as much as 1,000 times greater than normal. Besides the sulfur, they also detected large quantities of carbon in the plume. These findings highlight the role that volcanic eruptions play in the climate: particles containing carbon, often dark soot, have the potential to warm the atmosphere because they absorb sunlight. Sulfurous particles, on the other hand, cool the atmosphere because they reflect light. The results can also be interpreted as a natural test run for the idea of "seeding" the atmosphere with sulfuric acid as a coolant.

Kasatochi volcano, shortly after it erupted on August 7, 2008. The eruption enlarged the previously green island and covered it with gray ash.

Greedy Andromeda

Astronomers have never been so close to galactic cannibalism. An international team including researchers from the Max Planck Institute for Astronomy has observed stellar streams in the vicinity of the Andromeda Nebula in greater detail than ever before. The streams reveal that the galaxy has used its strong gravitational pull to consume smaller star systems. As part of the Pandas project, short for Pan-Andromeda Archeological Survey, the scientists discovered traces of six acts of cannibalism, including the remains of two as yet unidentified victims. They also found that Andromeda is already nibbling at the next one. A plume of stars extends toward Andromeda from the Triangulum Nebula. It was previously thought to be a companion to Andromeda and not in danger, but the plume indicates a past collision. Simulations created by the team show that Andromeda will also consume this nebula in the long run. (Nature, September 3, 2009)



The end in sight: A simulation shows that Andromeda – the circular disc to the right of the center – will eventually consume the Triangulum Nebula. In the stroboscopic projection, the shape of the Triangulum Nebula changes under the influence of the gravity exerted by the larger galaxy.

The Thymus Arrived with the Sharks

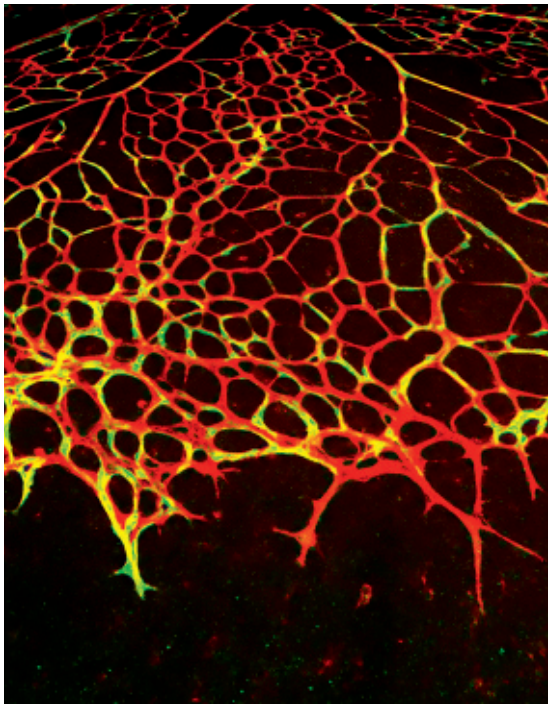
The thymus gland acts as a kind of training camp for special units in the immune system, where lymphocytes, a group of white blood corpuscles, specialize in offering an immune response to specific intruders. Scientists at the Max Planck Institute for Immune Biology in Freiburg have been tracing the origin and evolution of this organ. They found that the thymus first appeared around 500 million years ago based on already existing genes in sharks, the first animals in which it was shown to exist and in which also the crucial Foxn1 gene was first detected. Foxn1 contains the blueprint for a transcription factor that triggers the formation of the thymus. However, that on its own is not enough, because immature lymphocytes need to spend some time in the thymus in order to develop. In

Illustration: John Dubinski (bottom), photo: Chris Waythomas, AVS/USGS (top)

A Switch for Blood Vessel Growth

A known protein triggers the development of blood vessels and offers a starting point for the treatment of vascular diseases and cancer

Max Planck researchers have identified the biochemical instruction that spurs blood vessels into growth. It is a protein called Jagged 1. At the same time, they have explained how all the different players in blood vessel development interact. Biologists have known about Jagged 1 for some time. It performs functions in various organs. The protein binds to the notch receptor on blood vessel cells and acts like a switch for the growth of new blood vessels. As scientists at the Max Planck Institute for Molecular Biomedicine in Münster have established, Jagged 1 sets the switch to "on." The cell is then receptive to the VEGF growth factor and divides, creating a new vessel. The adversary to Jagged 1 is Delta-like 4, or Dll4 for short. This protein turns the switch to "off." Such detailed knowledge of the mechanism could help develop cures for various diseases. Systematically allowing blood vessels to grow could prevent or repair damage from a heart attack or stroke. It might also be possible to use the method to integrate transplanted organs into the blood circulation more quickly. On the other hand, the mechanism might help slow the growth of tumors if doctors can stop new blood vessels from developing in them. (Cell, June 12, 2009)



The veins of life: The development of new blood vessels is controlled by a cycle of growth-promoting and growth-suppressing factors.

Where the thymus originated – the organ (blue) first appeared among sharks 500 million years ago. There, it is located in the gullet; in humans it is above the heart. Up until puberty, a group of white blood corpuscles develops in the thymus, where they differentiate.

fact, the researchers in Freiburg found that sharks also have genes for signal proteins that attract undifferentiated lymphocytes to the thymus, where they receive their special training. The scientists hope that their findings on the evolution of the thymus will eventually benefit patients with immune diseases, as they could indicate which faults are the key to the weakness in their immune systems – faults that it may be possible to correct. (Cell, June 25 2009)

Photo: MPI for Immunology (left); MPI for Molecular Biomedicine – Rui Benedito (top)

Counting on Interference

Turning a weakness into a strength is something only therapists – and physicists – can do. An international team of researchers, including members of the Max Planck Institute for Quantum Optics, has proposed a way of using interference for quantum calculations. Up to now, physicists have been in agreement on the fact that it is possible to build a quantum computer only if its central processing units, the quantum bits, can be protected from interference. Quantum bits are very susceptible to interference, but it is very difficult to avoid, as any contact with the environment gives rise to interference. The researchers have thus worked out a calculating specification in which they use the contact with the environment for mathematical operations. However, this works only under one condition: the physicists must know exactly what the external influence does to the quantum bits. The interference could put the quantum bits in a state that holds the result of the calculation. The researchers' want to use their proposal to show their colleagues that it is worth asking whether a disadvantage can be turned into an advantage.
(Nature Physics, September 2009)

Bridges
That Bind Sand

A sandcastle is a complex entity – at least on the inside. That is where grains of sand, water and air combine to form an intricate structure. What holds them together is the subject of research being conducted by **Stephan Herminghaus** and his team at the **Max Planck Institute for Dynamics and Self-Organization** in Göttingen. Their work is also generating knowledge that can be applied in industrial processes, landslide prediction and oil production.

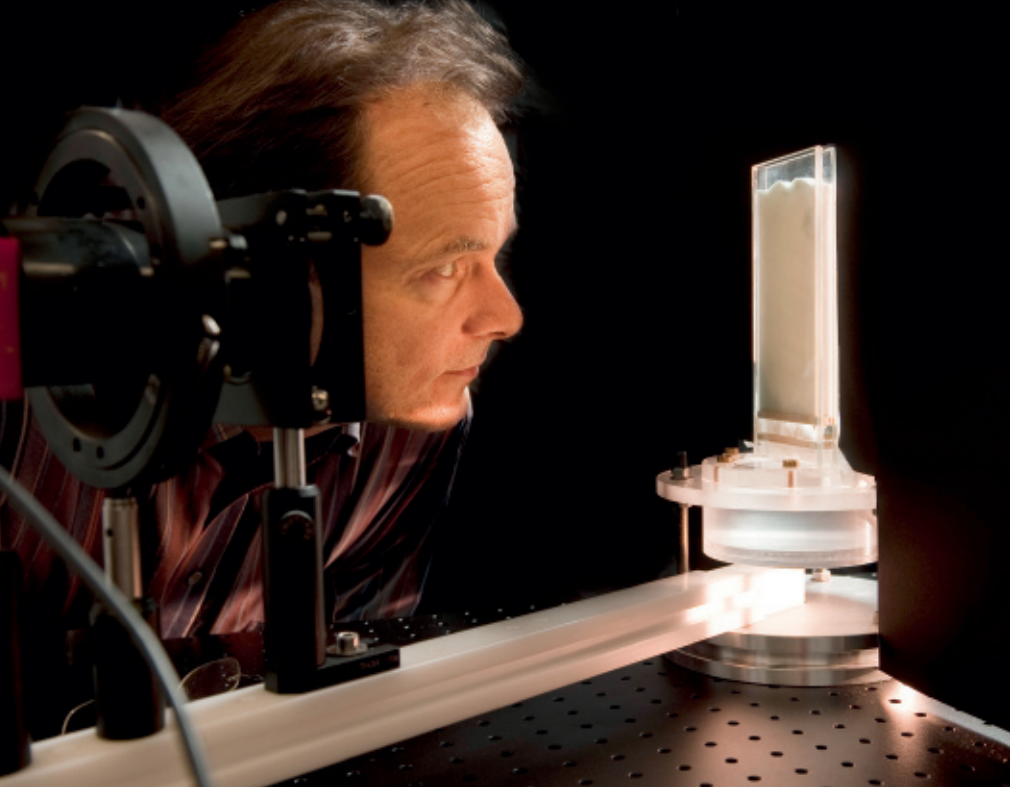
TEXT **CHRISTIAN MEIER**

Photo: Bastian Ehl

At first glance, it's not quite clear what sandcastles have to do with oil fields. However, as soon as Stephan Herminghaus and his team at the Max Planck Institute for Dynamics and Self-Organization in Göttingen had solved the long-unexplained mystery of the astonishing stability of sandcastles, the physicist received a phone call from oil giant BP.

But first things first: The story begins with pure scientific curiosity. Herminghaus was fascinated by an everyday wonder at the beach: the impressive alliance of sand and water. Out of an amorphous collection of grains that can trickle through the narrow neck of an hourglass or be scattered without the least resistance by a gust of wind, a liquid makes a stable and moldable building material for sandcastles and intricate sculptures. Stephan Herminghaus and his team were particularly puzzled by the following phenomenon: the firmness of the wet sand is largely independent of the quantity of water with which it is mixed. Sand that is barely wet is just as moldable and sta-

It's all about the mixture: Only when water and sand come together in the right quantities do the grains of sand stick together. This picture shows water that has been dropped onto a dish of sand, dispersing and wetting the sand.



Diffusion of light in granulate: Stephan Herminghaus checks a vessel filled with tiny glass beads. The scientist from the Max Planck Institute for Dynamics and Self-Organization is studying the diffusion of light through granulate in this experiment.

ble as sand that is almost saturated. This explains why no builder of sandcastles will ever be in need of a recipe for this building material.

In a bid to systematically get to the bottom of this phenomenon, the scientists in Göttingen studied a kind of model sand: glass beads with diameters of between 0.2 and 0.3 millimeters. Like most grains of sand, the glass beads consist of silicon dioxide. The model sand differs from the sand on the beach only in the fact that its grains form perfect spheres. The physicists wetted the glass-sphere granulate to different degrees and then measured the mechanical properties of the resulting paste, such as its tensile strength.

To achieve this, they formed a plug of the wet model sand in a cylindrical container, which they placed on a rotating plate. The scientists then gradually increased the speed of rotation until the granular plug was torn apart. From this rotational speed they were able to calculate the tensile strength. They also determined the granulate's resistance to shear forces. These are the forces that are at work when, for instance, a spoilsport attacks a sandcastle by pushing against the stronghold from the side, parallel to the ground. And finally, the scientists measured the strength of vibration the wet model sand had to be subjected to in order to make it flow.

SOLID GRANULATE MORPHS INTO AN ALMOST FLUID SLUDGE

The result: all three parameters are similarly dependent on the water content. Even the slightest addition of water causes them to rise abruptly, turning desert sand into paste. However, as the proportion of water rises further, they remain largely constant. Only when the water content accounts for around 20 percent of the volume do the three parameters decline again dramatically: the solid granulate becomes an almost fluid sludge. The granulate thus exhibits behavior similar to that of natural sand.

It thus really was suitable as a model, and not only for sand, but for what so often happens in landslides: when the material becomes too wet, it loses its stiffness. Why that sometimes happens very suddenly and also under widely varying water content, depending on the precise composition of the earth, is a complex problem. There is still a lot of work ahead for scientists who deal with such issues. The Göttingen-based Max Planck scientists started by devoting themselves to discovering just why it is that the sandy paste holds together so well with less water.

Investigating this matter was a fairly difficult business, as they had to look inside the granulate in order to understand the observations they made. "We wanted to know how the water distributes itself among the many narrow cavities between the beads," says Herminghaus. An optical microscope was of no help because the many beads reflect the light in all directions.

X-ray tomography provided the solution. As with a computer tomograph at the hospital, the wet granulate is illuminated from all sides by an X-ray beam. Since water, glass beads and air absorb the X-rays to different degrees, each image produces a well-defined silhouette. From the combination of images, a computer calculates the spatial structure of the specimen, and also shows how the water is distributed

Photo: Bastian Ehl (2)

The natural disaster at Nachterstedt in Saxony-Anhalt shows how important research into wet sand is: In July 2009, part of the bank of a mine lake suffered a landslide there, dragging two houses and three people into the depths.

throughout the space. Herminghaus's team went to the electron synchrotron in Grenoble and took such three-dimensional pictures for a number of different water contents.

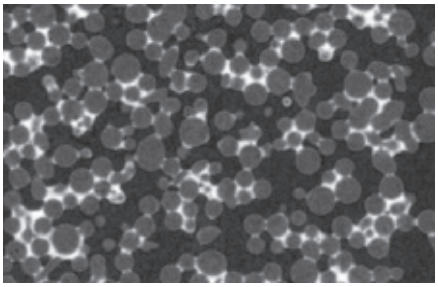
"When we looked at the images, we were astonished," reports Herminghaus. As the quantity of water increased, the spatial structure of the water's distribution between the grains of sand changed fundamentally numerous times, explains the scientist. "We asked ourselves how it could be that the mechanical properties didn't appear to notice this."

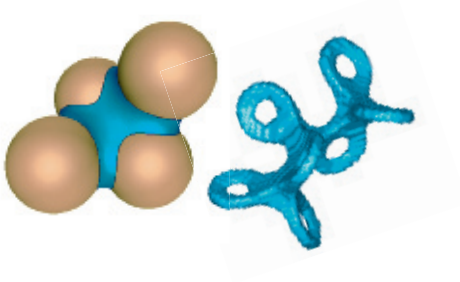
CAPILLARY BRIDGES FORM A RING AROUND THE CONTACT POINT

This is what happens in the granulate: Even with very little water added, "water bridges" immediately form between every two adjacent grains. The water attempts to cover as much glass as possible because the water molecules are attracted by the wall of glass. Consequently, the water moves to the places where it can touch two spheres at the same time: to the points of contact between two beads. The resulting liquid bond between two spheres is known by physicists as a capillary bridge. It forms a ring around the contact point.

Starting from about 3 percent water content, these capillary bridges begin to fuse with one another, resulting in the creation of individual "water nests." If more water is added, the little nests merge to form bigger nests. At around 10 percent water content, they become so large that they form waterways within the specimen, reaching from one end to the other. "A paramecium could swim from one end of the specimen to the other," says Herminghaus.

"We couldn't intuitively understand why these complex transformations caused no changes in mechanical stability," explains the physicist. The only thing the scientists found easy to understand was what happened when just a little water was added, provided there were only individual water bridges in the granulate. The interface between the capillary bridge and the air is concave, arching down into the water. This creates a negative pressure in the water, which draws the beads together. >

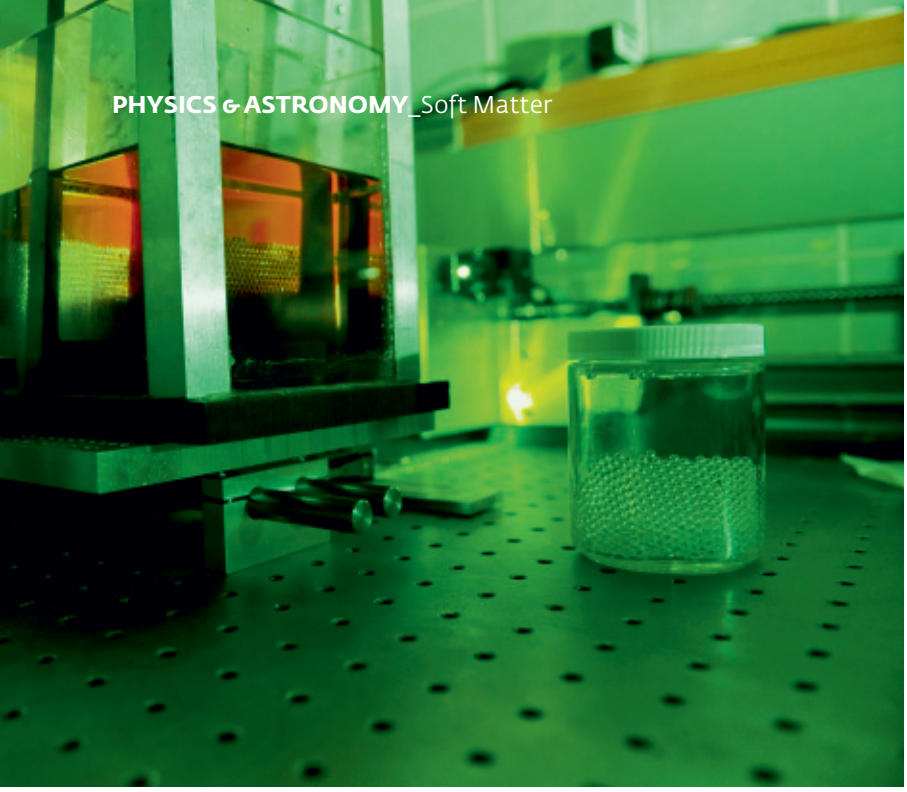


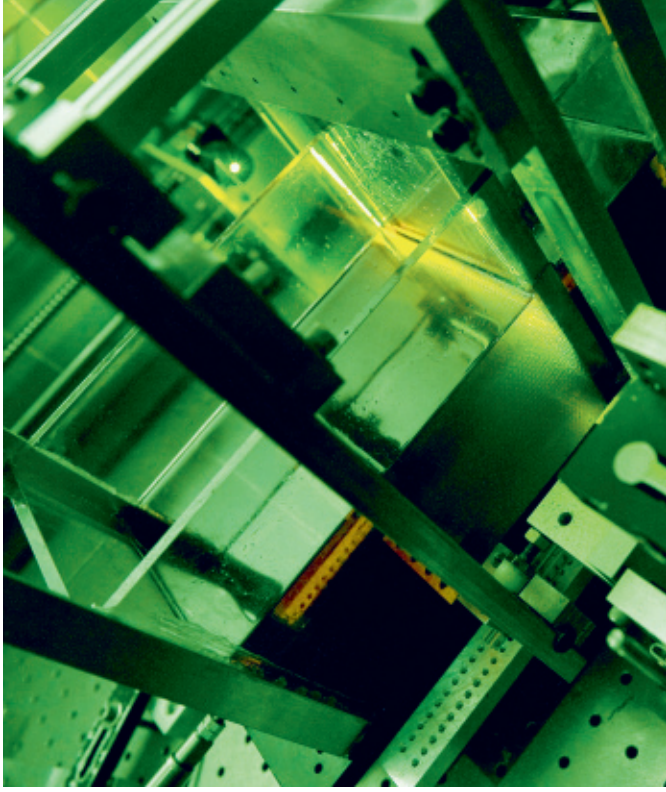


top — Cross-section of a wet granulate. The image was taken with the help of X-ray tomography; the grains are gray, the water is white and the air is black.

bottom — The computer simulation on the left depicts nests of liquid (blue) and spheres of granulate (yellow); the partial image on the right shows the tomographic representation of individual nests of liquid.

Photo: dpa Picture-Alliance (top); MPI for Dynamics and Self-Organization (bottom, 3)





Complex experimental setup: Doctoral student Frank Rietz watches the package of spheres compact in a shear chamber – a type of open-top aquarium whose glass walls periodically tilt back and forth, "shearing" the glass spheres between the plates.

If more water gets into the granulate, it flows into the capillary bridge, making it larger. The concave arch of the water surface thus becomes less pronounced and the negative pressure decreases. However, the drop in suction is balanced out by the increase in the area in contact with the glass spheres with which it interacts. The force of attraction between the beads as exercised by the capillary bridges thus remains constant – and with it, the stability of the granulate.

"But things get exciting when two growing capillary bridges blend into one," says Herminghaus. This happens whenever two neighboring capillary bridges touch. In this case, they merge and fill the whole of the cavity between three spheres with water. Given that the three spheres are usually in contact with each other, there is a third capillary bridge, which inevitably merges with the other two: a trio of capillary bridges results. Because the spheres involved are about the same size, the trio always forms when the capillary bridges reach a very specific size, in other words always with the same amount of negative pressure – what scientists call fusion pressure.

A similar thing occurs when the capillary bridge trio combines with other bridges or other trios to form larger nests. "All of this can be very nicely tracked and confirmed with tomography," says Herminghaus. The scientists thus understood what happens when more than 3 percent water is added: no new bridges are formed, but rather, the existing bridges grow together to form nests.

THE PRESSURE ACTS FROM ALL SIDES

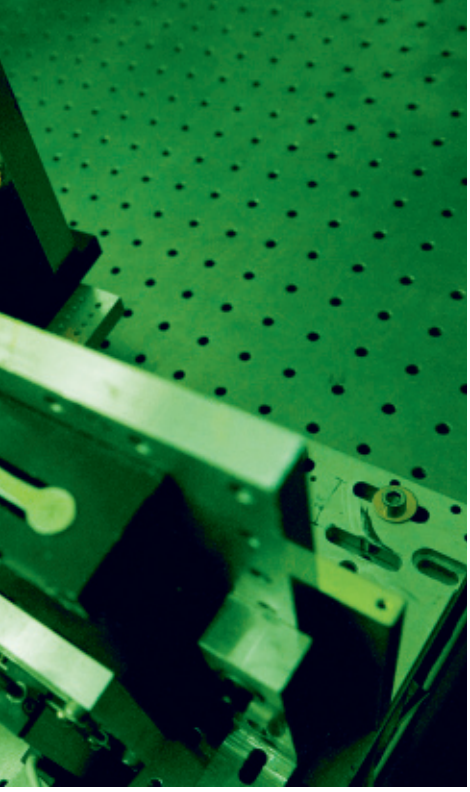
But one mystery remained unsolved: Why does the negative pressure have the same effect on the stability of the material when the majority of the grains appear to be surrounded by water? In this case, the pressure on the spheres floating in the water acts from all sides and should be completely equalized. All things considered, there would be no suction left to hold the granulate together.

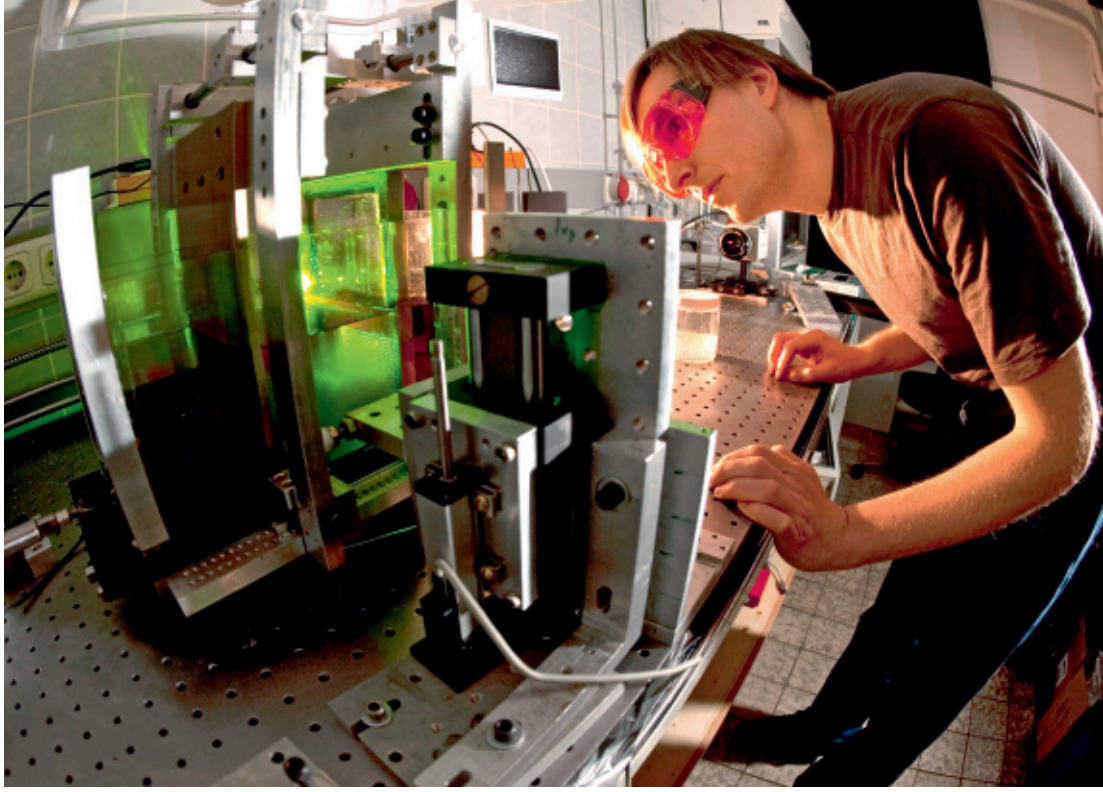
Here too, it was X-ray tomograms that provided the crucial clue. What they showed was that many air-filled cavities still remained. "The granulate is soaked, not in a nest, but in an intricate water sculpture," explains Herminghaus. All of the grains are in contact with water surface and are mechanically stabilized by its surface tension.

A beaker full of glass spheres is, of course, not the same as natural sand, because grains of sand are anything but perfect spheres. Nevertheless, the physicists from Göttingen are convinced that their explanatory model also applies to sand. Not only did they discover that the mechanical properties of wet natural sand depend on the volume of liquid to an almost equal extent as do those of model sand, but as the X-ray tomogram showed, their water nests also form a very similar structure.

Manufacturers of tablets have long been aware of the fact that the mechanical properties of wet granulates do not change – even when their liquid content varies. Pharmaceutical producers use mixing machines to blend the carrier powder and the active ingredient with a liquid in order to make pills. "Over a broad moisture range, the mixers always consume about the same amount of power," re-

Photo: Bastian Ehl (3)





ports Herminghaus. The resistance that the mixture exerts on the mixers does not change significantly as it becomes wetter.

Herminghaus stresses that his research results are important for more than just sand sculptors and pill manufacturers. "The findings can probably be applied to most sands that occur in nature and a large number of other sediments," says the physicist. This is because most natural sediments are fairly well "sorted," as geologists say, by their lengthy transportation in water and wind. In plain text, this means that all of the grains are approximately the same size. For instance, the flow velocity of a river determines the size of the grains that settle on the riverbed. "This being the case, our findings could contribute to a better understanding of landslides and perhaps even enable them to be predicted," says Herminghaus.

Herminghaus's research also fits into another context, which is an area of burning interest to physicists the world over: namely the question of whether there are overriding, universal laws for complexity and self-organization. Or, putting it another way: are completely different systems, such as wet granulates, ant colonies and the human brain, governed by the same rules of complexity? Such rules, many physicists hope, would make it easier to understand the physics of highly complicated phenomena.

THE RIGHT QUESTIONS PRODUCE SIMPLE ANSWERS

The physics world is split on this question. "I've spent a lot of time on this issue and have come to the conclusion that there are no such universal laws," says Herminghaus. He believes the search for generally valid formulas merely serves to hold people back. "Each complex system is a case in itself that we, as scientists, must consider anew," he says.

Herminghaus has nevertheless developed a kind of methodology for getting closer to complex systems. He approaches them rather like a criminologist: "I put myself inside the system, as it were, and try to visualize how it works," explains the physicist. The method also involves a sort of intelligent interrogation technique: "If you ask a complex system the right questions, it gives you surprisingly simple answers," says Herminghaus. He goes on to explain that it often shows you very simple rules by which it works. The job of the scientist is to find the right questions.

How surprisingly simple the answers can be was demonstrated by the group in Göttingen, again using a wet granulate of glass spheres. They examined how it reacted to different degrees of vibration. The scientists poured the granulate into a flat, cylindrical, plastic container and placed it on a shaker. They then changed the energy and the acceleration of the vibration by varying either the shaker's amplitude or its frequency.

The behavior the wet granulate exhibited was highly complex. It went through similar phase transitions as those experienced by a solid that is melting as a result of heating, and whose particles ultimately evaporate into a gas. Similarly, at low acceleration, the grains lay closely packed together and remained motionless, which corresponds to the solid state.

Different grain size, different properties – and a rich selection: Doctoral student Mirko Lukovic collects the appropriate material for an experiment in the lab. It is ready and waiting in the form of all kinds of sand, granulate and glass spheres, tidily filled into bottles.

As the acceleration increased, they transitioned into a sort of liquid phase in which the particles moved faster and migrated through the granulate.

Things got really interesting when the scientists increased the energy input during the stage of high acceleration. In this case, a third gaseous phase manifested itself in which the grains moved very fast and free. This gas phase existed in the middle of the plastic dish. Around it, a ring of the liquid phase remained, where the particles moved much slower. Since the median particle speed provides a measure of the temperature, this dual phase had two temperatures. A truly complex occurrence, and one that is unlikely to be faced when boiling water on the stove.

THE COMPUTER BRINGS LIGHT TO COMPLEX SYSTEMS

The obvious assumption is that such behavior depends on many different properties and details of the wet granulate. However, the scientists in Göttingen showed in computer simulations that this is not the case. "We asked ourselves how the phase transitions depended on the behavior of the force with which a capillary bridge pulls on the beads when they move apart," explains Herminghaus. The bridge is like a spring that pulls tighter and tighter as the glass spheres try to move further apart, and that ruptures at a certain tensile force.

The scientists simulated this behavior on the computer and obtained a phase diagram that corresponded fairly well with what they had observed. They then made a bold assumption: they conjectured that the behavior of the system did not depend on how the tensile force of the capillary bridge changed as a function of the distance of the spheres, but that it depended solely on the energy one had to input in order to pull the bridge apart.

And they were right: when they repeated the simulation using this assumption, the scientists obtained the same phase diagram as they had from the previous simulation. In the energy that was needed to break the capillary bridge, they had found the crucial lever that described the behavior of the wet, shaken granulate.

As far as Stephan Herminghaus is concerned, this example shows where one of the keys to understanding complex systems lies: in identifying the fundamental properties of the system and blanking out the many irrelevant details. "In its fundamental aspects, every system is simple," says Herminghaus. "The art of finding this fundamental aspect is not something that can be learned through schooling – it can come only through years of experience."

NEW KNOWLEDGE TO MAKE EXPLORATION MORE EFFICIENT

"I believe that it is this ability that convinced BP to fund our research," says the physicist. The oil conglomerate has a problem, namely: oil fields contain residues that are impossible or at least difficult to exploit. When the oil stops bubbling up to the surface on its own, the oil producers give it a helping hand by pumping water into porous rock in a bid to force the oil out. "Nests" of oil form in the underground rock and no longer reach the conveyor pipes – roughly half of the oil stays in the depths.

Photo: Bastian Ehl (3)

"These nests have a very similar structure to the water nests in a wet granulate and should follow similar principles," says Herminghaus. The situation becomes even more complex when it comes to storing carbon dioxide in empty oil fields. In this case, it is not two but three components – carbon dioxide, water and residual crude oil – that need to be squeezed in between the grains. "There is an enormous amount of research still to be done here," says Herminghaus.

BP SUPPORTS THE RESEARCH FINANCIALLY

"Ensuring sustainable supplies of energy for the world is a multifaceted problem," says Herminghaus. "It is our job as scientists to deliver the knowledge that can provide the basis for the right decisions to be made." BP is now funding the work of his department for a period of ten years to the tune of USD 1 million per year. However, the Göttingen-based scientists have agreed with the oil company that they will continue to determine their research program themselves. "We did not want to have a research agenda imposed on us," says the physicist. "It's nice and actually encouraging that even major industrial corporations like BP accept this."

And so the research at the Max Planck Institute in Göttingen continues as planned. The next thing that Herminghaus wants to study is new types of model sand. These consist of tiny platonic bodies, such as tetrahedrons and octahedrons. "The objective is to understand how the grains' shape influences the properties of the wet granulate," says the physicist. In the process, he and his team are moving closer to a precise understanding of how moisture behaves in natural sands whose particles differ in shape. And they may also learn more about how oil behaves in the irregularly shaped pores of rocks. ◂

GLOSSARY

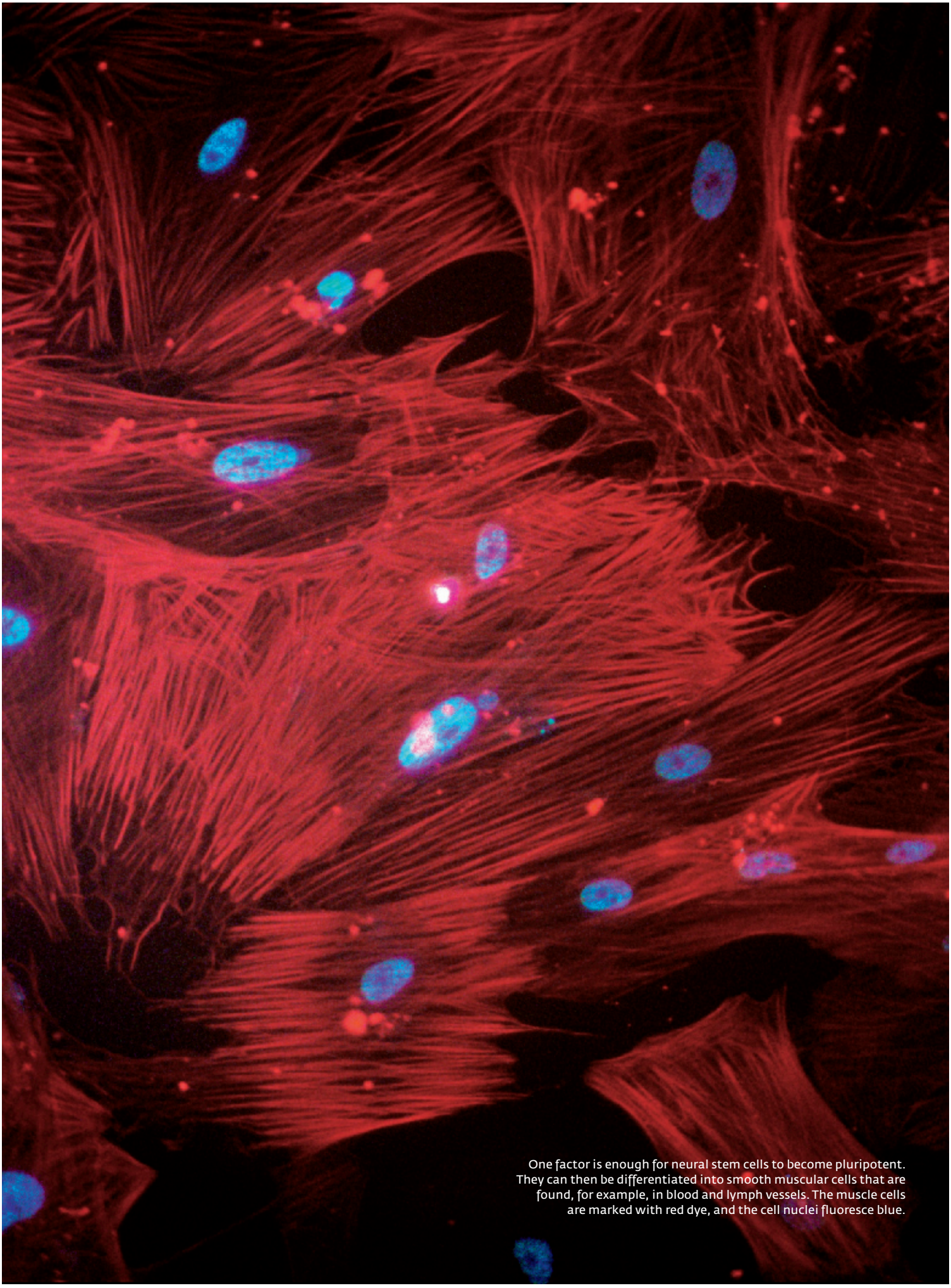
Silicon dioxide
General term for compounds with the chemical formula SiO_2; subsumes modifications of silicon oxides. There is crystalline and amorphous SiO_2; the best-known crystalline form is quartz.

X-ray tomography
An imaging process for generating three-dimensional images of a specimen. X-ray absorption images are taken of the specimen at a large number of different angles. A powerful computer can then reconstruct the three-dimensional structure from these images (computer tomography).

Capillary bridge
A liquid bond that causes the grains to interact through the force of the surface tension.

Platonic bodies
Completely regular bodies consisting of equally sized, equilateral and equiangular polygons. Exactly the same number of surfaces meets at each corner of such bodies.

Phase diagram
A schematic representation of phases and their phase boundaries as a function of temperature, pressure and composition. Such diagrams can describe materials in their solid, liquid and gaseous states.



One factor is enough for neural stem cells to become pluripotent. They can then be differentiated into smooth muscular cells that are found, for example, in blood and lymph vessels. The muscle cells are marked with red dye, and the cell nuclei fluoresce blue.

Potency Boost for Cells

It is one of the dogmas of biology that no specialized cell could ever change its nature and become something different. However, the researchers working with **Hans Schöler** at the **Max Planck Institute for Molecular Biomedicine** in Münster have succeeded in using a single factor from adult brain stem cells to generate the cellular jacks-of-all-trades on which regenerative medicine is pinning its hopes.

TEXT **KLAUS WILHELM**

Seen from a purely optical perspective through a microscope, the test tube revolution doesn't appear all that spectacular. However, something extraordinary recently occurred in the cells – which are identifiable as small dots – in the laboratory of the Max Planck Institute for Molecular Biomedicine. Just two weeks ago these were skin cells from a patient with Parkinson's disease – differentiated somatic cells that carry a genetic defect – and were harvested from a patient by doctors at the Dresden University of Technology. The cells were then handed over to the scientists working with Hans Schöler in Münster. This group provided the cells with a mixture of nutrients and growth factors, and also infected them with virus particles loaded with four genes bearing the cryptic abbreviations Oct4, Sox2, c-Myc and Klf4.

Over the course of about one month, these four genes transformed some of the skin cells into "human induced pluripotent stem cells," embryonic stem cells without the embryos, so to speak. Stem cells are the cells from which all 200 cell types found in the human organism develop – cells in the skin, bones, kidneys, stomach, and so on. Moreover, scientists hope that these cells will make it possible to trace the emergence of Parkinson's disease with a view to developing suitable drugs more easily and effectively. In this cutting-edge branch of research involving induced pluripotent stem cells, known as iPS cells for short, or "ipses" in laboratory jargon, "we are without doubt one of the world's leading research groups," says Hans Schöler. Very few teams have succeeded in reprogramming "diseased" human cells up to now; in these cases, differentiation into disease-specific nerve cells was successfully achieved for two rare brain and muscle disorders.

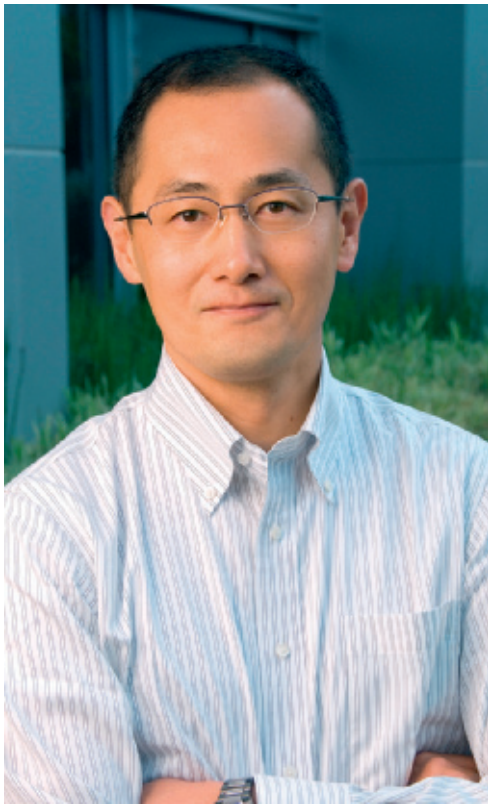
FRESH REPLACEMENT CELLS FOR DISEASED TISSUE

Up to now, visionaries could conceive of removing cells from patients suffering from cardiac infarction, diabetes, Parkinson's and many other diseases, reprogramming them into iPS cells and replacing the diseased or injured tissue with the fresh and vital cells. This would be the ideal solution and, from a purely technical perspective at least, one that no longer seems utopian. Moreover, it would also eliminate one of the main problems faced by regenerative medicine: the cells used in the treatment originate from the patient and are thus not rejected by the recipient's immune system. There is, however, one catch: from today's perspective, this kind of individual form of regenerative medicine entails enormous effort and expense – and is conceivable only with the help of automation.

As recently as 2005, Hans Schöler would not have bet a single cent that the impossible would become possible within the space of just one year, that the skin cell of a mouse would be transformed into a pluripotent stem cell by genetic manipulation alone. What this does, in effect, is turn the biological clock back. It is one of the dogmas of almost a century of modern biology that no specialized cell could ever change its nature and become something different. Once a cell has differentiated, it deactivates all of the genes in its genetic program that allow it to divide without restraint. At the same time, it switches on the genes that specialize it, making a skin cell into a skin cell.

Cells basically manufacture proteins and other molecules that they need on the instruction of the genes. In humans, only a portion of the 25,000 or so genes are switched on in every cell. Cells control the activity of their genes via complicated signaling pathways involving large numbers of proteins. This requires, above all, the services of tran-

Photo: MPI for Molecular Biomedicine – Jeong Beom Kim



The pioneers of stem cell research: Shinya Yamanaka from the University of Kyoto (left) succeeded for the first time in transforming mouse skin cells into cells that are very similar to embryonic stem cells. Hans Schöler from the Max Planck Institute for Molecular Biomedicine (right) managed to propagate these pluripotent jacks-of-all-trades from mouse brain cells using a single factor (Oct4).

scription factors – usually proteins that switch genes on or off. But even the transcription factors are coded by genes and are controlled, in turn, by a complex information network.

KICK-START FROM JAPAN

Shinya Yamanaka from the University of Kyoto experimented with the genes for some transcription factors in 2006. When Hans Schöler describes the pioneering achievements and the persistence of his Japanese colleague, respect shines through his every word, despite the intense competition in the field of international stem cell research. "The program of the somatic cells appeared to be so definite," explains the Max Planck scientist, "that most researchers believed this could never work." However, the unwavering Yamanaka provided the kick-start for what has since been unfolding "at breakneck speed" in the world's stem cell laboratories.

With the help of viruses that acted as gene ferries of sorts, the Japanese scientist transported 24 genes for transcription factors in all conceivable combinations into skin cells. "The fact that this kind of experiment could be carried out successfully with 24 genes was amazing in itself. I would have thought it was very unlikely to work," says Schöler.

In a series of follow-up experiments, Yamanaka reduced the number of genes to just four: the quartet Oct4, Sox2, c-Myc and Klf4, all of which are normally switched off in skin cells. In the end, he succeeded in harvesting pluripotent stem cells. Although the process is not exactly efficient – only one in every thousand to one in every ten thousand skin cells is reprogrammed – it works! A new chapter in stem cell research began with the unlimited self-renewing iPS cells and continues to develop at an ever-increasing pace.

As far back as 1998, US scientist James Thomson succeeded in reproducing human embryonic stem cells (ES cells) in the laboratory, which marked the very first milestone. Pluripotent stem cells usually grow only at a very early stage in embryonic development: they collect in the interior of blastocysts, spherical structures that comprise between 150 and 200 cells and that form just under one week after the fertilization of an ovum and in the first eight or so cell divisions thereafter. The pluripotent stem cells supply the growing and increasingly complex embryo with all of the different cell types it needs to grow muscles, internal organs, the brain, arms, legs, and so forth.

Back in 1998, it took enormous skill and ingenuity to propagate the extremely sensitive embryonic stem cells – as the pluripotent stem cells are known when harvested from the embryo – in the laboratory in a way that ensured they would remain unspecialized and genetically intact. Today, there are over 500 human embryonic stem cell lines and the trend is rising. However, these cellular jacks-of-all-trades also raise ethical issues, as their harvesting results in the destruction of the embryo. This was among the reasons why, in the early years of this century, German scientists in particular concentrated on adult stem cells, which can be harvested from various sources within the mature adult body. However, these cells are not pluripotent and can therefore differentiate to form only a few specific cell types.

Yamanaka's feat was a timely one. Not only are his iPS cells pluripotent, they have also succeeded in defusing

Photo: dpa Picture-Alliance (left); MPI for Molecular Biomedicine – Sarah Eick

» Oct4 appears to command the reprogramming of cells like the captain of a ship. The other genes are the sailors.

the stem cell debate, as they can be harvested without the use of embryos. However, one major problem remained: if these iPS cells are injected into mice, many of the animals develop tumors. The reasons for this are clear. First, the viruses with the four integrated genes Oct4, Sox2, c-Myc and Klf4 slot randomly into the genotype of the mice. As a result, things like cancer genes can be activated or anti-cancer genes destroyed. Second, the increased quantity of the c-Myc gene promotes the growth of tumors. "For this reason, the Yamanaka process is out of the question for therapeutic application in humans," explains Hans Schöler.

So the Max Planck researchers diligently searched for cells in which one or another of the four reprogramming genes is naturally active. Jeong Beom Kim and Holm Zaehres actually found adult stem cells in the brains of fully grown mice that develop into different cell types of the central nervous system. The Sox2 and c-Myc genes are already switched on in these cells. The two cell biologists quickly demonstrated that a virus cocktail containing just Oct4 and Klf4 can reprogram these cells into iPS cells.

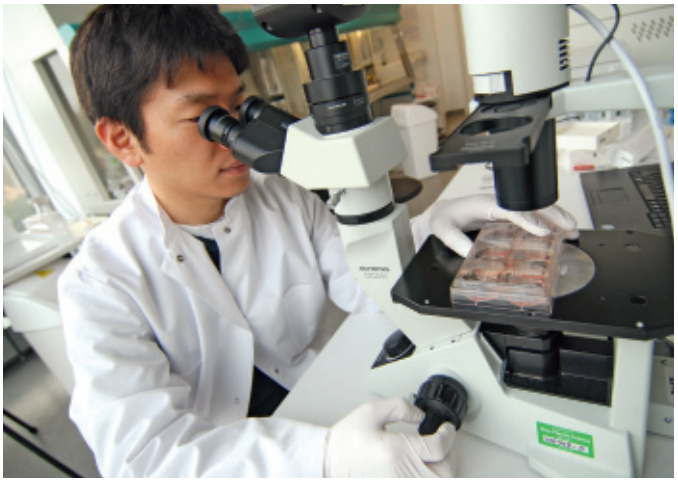
TRANSFORMATION REQUIRES PATIENCE

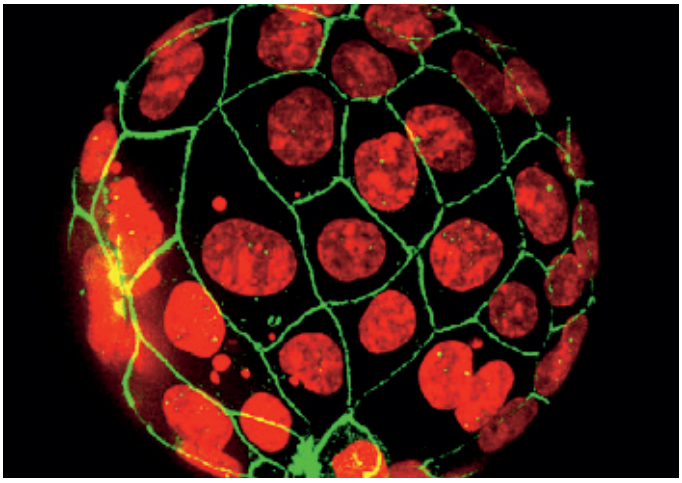
The next coup from the stem cell laboratory in Münster followed just a few months later: Oct4 alone is sufficient to grow iPS cells from adult mouse brain stem cells – as long as the process is approached with patience. If only two reprogramming genes are inserted into the cells, the transformation takes at least two weeks. If Oct4 alone is used for the cellular relaunch, three to four weeks will pass before the researchers can harvest pluripotent cells. And the Münster-based scientists even succeeded in applying these results to stem cells from the human brain.

It is clear from this "that Oct4 appears to command the reprogramming of cells like the captain of a ship," explains Hans Schöler. "The other genes, such as Sox2, c-Myc and Klf4, are the sailors." Despite the fact that he has been working on this molecule and its functions for a good two decades, Schöler could previously only assume that Oct4 played such a central role in pluripotency.

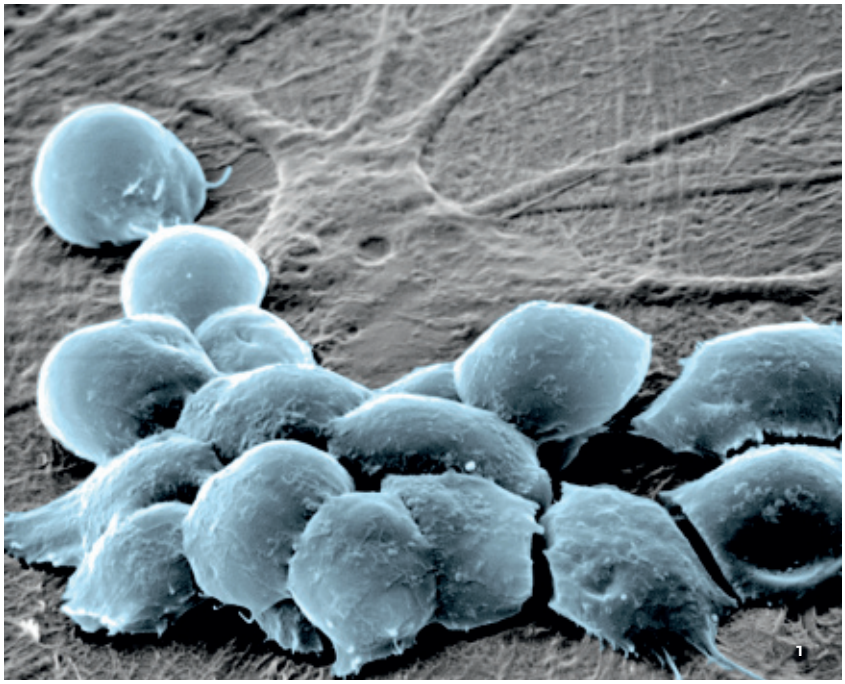
Strictly speaking, the biologist was the first to discover Oct4 and related molecules in mouse egg cells at the Max Planck Institute for Biophysical Chemistry in Göttingen in the late 1980s. Over the years that followed, it emerged that Oct4 is active in all cells "that convey one generation into the next and that are thus virtually immortal," says Schöler. According to the 56-year-old

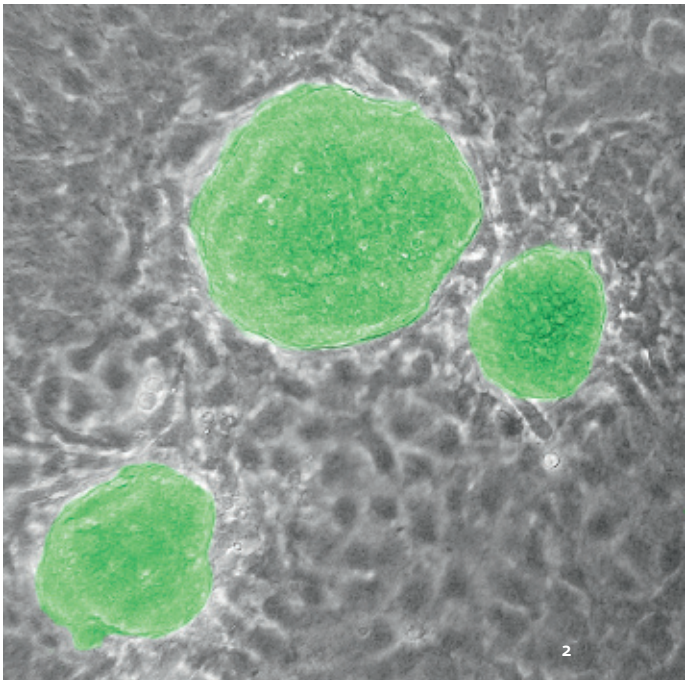
Researcher Jeong Beom Kim (left) examines a mouse embryo at the blastocyst stage (right), which forms around five to six days after the fertilization of the ovum. The cell-cell contacts of the outer cell layer are indicated in green, the nucleus in red.





Photos: MPI for Molecular Biomedicine – Dirk Hans (left); MPI for Molecular Biomedicine – Guangming Wu





scientist, Oct4 also provides a key to the in-depth understanding of the biology of cell reprogramming. "The captain must always be on board," says Schöler, "but the sailors can be replaced." It appears that Oct4, Sox2 and the other genes or proteins involved regulate each other mutually. Exactly how this occurs, however, remains a mystery for the time being.

DISPENSING WITH VIRUS FERRIES

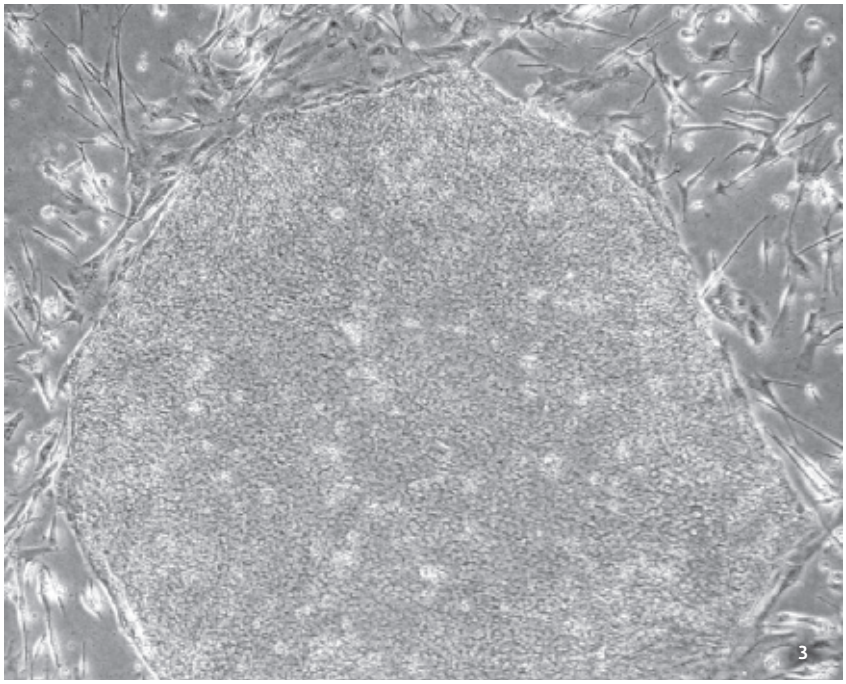
Nevertheless, the reprogramming technology is rapidly becoming more suitable for practical use. In spring 2009, scientists in California reported, in conjunction with the Max Planck team, that they had transformed cells without viruses and their genetic reprogramming load into iPS cells. Instead, the scientists transported the corresponding proteins directly into the skin cells of mice. This is no mean feat, as proteins are extremely large – on the molecular scale, at least. One particular trick proved helpful: the scientists linked a small chain of the amino acid arginine to the proteins, which had been specially produced in bacteria. This molecular "ticket" smoothes the way for their entry into the cells.

The stem cell experts channeled the cocktail of Oct4, Klf4, Sox2 and c-Myc proteins into the skin cells a total of four times. Without the repeated application, the cells would always have returned to their original state. The researchers also added a so-called small molecule – a low-dose chemical substance that helps the proteins fulfill their function – to the mix. When more than one month had passed, the researchers observed sure signs of reprogramming in some of the cells. It was thus proven for the first time that it is possible to dispense with the risky use of virus ferries. As far as we know today, the addition of the proteins does not involve any risk – not least because the proteins are broken down very quickly in the cell interior. The researchers named their new creations "piPS": protein-induced pluripotent stem cells.

Even if large protein molecules are still required, one of the core problems of cell reprogramming appears to have been solved in terms of the therapeutic application of the method to humans (Korean researchers have already described the method for human cells). "We now have a foot in the door, but the method needs to be made significantly more efficient," stresses Hans Schöler. "I'm just waiting for someone to implement the reprogramming process using only small molecules," in other words, exclusively with substances that can easily be smuggled into cells and can switch on the most important reprogramming genes, thus ensuring their pluripotent state.

"It wouldn't surprise me if this happens soon," says the Max Planck Director. In contrast to the transportation of genes into cells, the duration and strength of the effect of small molecules can be controlled with far greater precision: as soon as the cells are reprogrammed, the normal developmental program can unfold within them. In contrast, viruses, once smuggled in, remain in the genotype forever – with all of the corresponding risks.

In the meantime, Schöler has already sounded the next drumbeat: cells that reprogram almost automatically into pluripotent stem cells have been isolated from the testes, an organ with highly surprising peculiarities. The testes continue to produce functional sperm even into old age. But this is not the only reason why scientists suspect they may be able to find ideal source material for reprogramming there.



1 The research on iPS cells is developing at a rapid pace: Embryonic stem cells – in this case from a mouse – are gradually being replaced by induced pluripotent stem cells harvested from differentiated cells.

2 To reprogram so-called adult cells into pluripotent jacks-of-all-trades, the researchers initially needed four factors (Oct4, Sox2, Klf4, c-Myc). These stem cells were produced in this way from mouse connective tissue cells.

3 Because these factors can cause cancer when they are transported into cells, researchers aim to do without them, if possible. The scientists are playing it safe here: this colony of human induced pluripotent stem cells was already cultivated through the addition of Oct4 alone.

Various groups had already stumbled on cells in the testes and had stimulated transformation processes in them. For example, scientists working in Tübingen succeeded in isolating cells that are capable of transformation from human testes tissue. However, it has not yet been established definitively whether the cells reprogrammed from this source are actually pluripotent.

The Max Planck researchers have now tracked down extremely rare germline stem cells in the testes of mice: only 2 to 3 out of 10,000 cells from the testes are of this type. "We knew that Oct4 is switched on to a limited extent in these germline stem cells," says Schöler, "because it also plays an important role in the formation of sperm."

In other words, the captain of the pluripotency is actually present but is

ARE THEY REALLY PLURIPOTENT?

Researchers constantly report that they have reprogrammed somatic cells or adult stem cells into pluripotent stem cells (iPS cells). Sometimes, however, they fail to provide irrefutable proof of the pluripotency of the reprogrammed cells – even when the corresponding results have been published in prestigious scientific journals. Reliable proof of pluripotency is based on various tests:

- Proof of marker genes: Genes like Oct4, which are silent in differentiated somatic cells, are switched on in iPS cells.
- Proof of teratoma formation: If pluripotent iPS cells are injected under the skin of mice, a special form of tumor, known as a teratoma, develops. This growth contains different types of somatic cells and is similar to embryonic tumors with the formation of the three "germ layers" from which different tissue types develop.
- Proof of cell differentiation: In principle, all of the body's cell types can be produced from iPS cells in the Petri dish. Here, too, it is essential that cells from the three germ layers be cultivated and their functionality proven.
- Proof of chimera formation: Scientists inject the iPS cells into mouse embryos and prove that they are contained in the growing organism. The iPS cells are usually marked with a fluorescence gene that makes them visible under the microscope as luminous tissue. Demonstrating the presence of iPS cells that have matured into cells of the germline is viewed as particularly important in that it proves that the cells can convey their genetic information to the next generation.

The ultimate proof of the basic pluripotency of iPS cells was provided by Chinese researchers in summer 2009 based on a particular variant of chimera formation: the researchers generated viable mice from reprogrammed somatic cells that originated almost 100 percent from the iPS cells.

Photo: MPI for Molecular Biomedicine (3), Katherina Psathaki (left), Holm Zaehres (center), Jeong Beom Kim (right)

» We now have different systems for generating pluripotency, and they are improving all the time.

not yet fully awake and in a position to activate the sailors. The scientists roused Oct4 with the help of special cultivation conditions. They noticed something important when they cultivated the cells from the testes: when neighboring germline stem cells were a certain distance apart, they reprogrammed into pluripotent stem cells within a period of two weeks and there was no need for the introduction of proteins, foreign genes or small molecules.

"We now have different systems for generating pluripotency," summarizes Schöler, "and they are improving all the time." Moreover, researchers are finding more new sources of adult stem cells in the human body that can probably be reprogrammed successfully and are easy to access. For example, adult neural stem cells were recently found in the palate. It would also appear that the olfactory mucosa in the nose constitute another optimal source of these cells. This all bodes extremely well for the prospect of eventually fulfilling the dream of ethically acceptable and medically low-risk and effective regenerative medicine.

However, Schöler would first like to await the results of clinical studies carried out by doctors using "classical" embryonic stem cells. The first study of this nature is due to start soon in the US and will involve paraplegic patients. The main aim of the planned pilot study, which has not yet been approved by the US Food and Drug Administration (FDA), is to clarify the risks associated with treatment using nerve cells derived from human embryonic stem cells. "Based on the preliminary tests carried out on animals, it is unlikely that tumors will form," says Schöler who is hopeful for the success of the study. In paraplegic animals, the injected neural derivatives of embryonic stem cells matured further at the injured locations in the spinal cord and formed healthy tissue.

UMBILICAL CORD BLOOD HELPS THE RESEARCHERS

Corresponding studies on patients based on derivatives of human embryonic stem cells could help scientists find the optimum design for future studies involving iPS cells. Ideally, this would involve the harvesting of cells from the diseased person, which could be transformed in the test tube and then differentiated as required into healthy somatic cells – such as heart muscle cells for cardiac patients or nerve cells for Parkinson's patients.

However, due to the presumably impractical level of effort and costs associated with this approach, Hans Schöler is working with the umbilical cord blood bank in Düsseldorf, which contains thousands of samples of blood from umbilical cords. This stem cell source has two advantages. First, umbilical cord blood contains special stem cells, known as umbilical cord derived stem cells. In addition, based on a kind of immunological profile, it would be possible to establish which samples from the umbilical cord blood bank would be particularly well suited to a potential recipient. Furthermore, the genetic material contained in these cells is young and therefore contains few defects.

These are all ideal preconditions for taking samples that largely cover the immunological range of the population and reprogramming the adult stem cells they contain. The researchers would then produce precursor cells for specialized cells – ranging from skin to heart muscle cells – from the iPS cells. These could then be implanted in patients with the corresponding disorders. "This would all take place within a clear framework," assumes Schöler, "involving perhaps 10,000 samples for the entire German population." Such a system would be affordable, practicable and efficient.

However, it will take many more years before this can come to pass. The Max Planck researchers have taken the first steps on this long journey: they have reprogrammed stem cells from human umbilical cord blood into iPS cells – still using the Yamanaka method. They now plan to do the same using the protein method. "We are now working intensely on this," says Schöler. ◂

GLOSSARY

Differentiated cell
A cell that is specialized to fulfill a specific task in the body.

Induced pluripotent stem cells (iPS cells)
Stem cells that are harvested from somatic cells and that can differentiate into as many different types of somatic cells as embryonic stem cells can.

Adult stem cells
Stem cells that are also present in numerous tissues in adults. They are not pluripotent, but some can be transformed into iPS cells.

Umbilical cord blood stem cells
In late pregnancy, blood production migrates from the liver and spleen to the bone marrow through the blood of the baby. Stem cells having a particularly high reproductive capacity are thus also found in the umbilical cord blood at birth, and can differentiate into a particularly large number of somatic cells.

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Unusual sounds at the Max Planck Institute for Iron Research: Dierk Raabe tests the acoustics of the staircase. The French horn was his main instrument at the Wuppertal Conservatory. The only thing he didn't like was polishing the corrosion-prone metal.

A Commuter between **Metallic Dimensions**

As a 16 year old, **Dierk Raabe** studied double bass and French horn at the Wuppertal Conservatory. Today he pursues the quantum revolution of materials science as Director at the **Max Planck Institute for Iron Research** in Düsseldorf.

A PORTRAIT BY **ROLAND WENGENMAYR**

Had the career dreams of the young Dierk Raabe come true, he would not now be sitting in the conference room at the Max Planck Institute for Iron Research in Düsseldorf with light streaming through the windows. Fittingly, heavy iron girders reminiscent of the Eiffel Tower provide a solid framework for the Bauhaus architecture, which has been modernized with a great deal of glass. For Raabe, it was love at second sight with metallic materials. His first intense contact was rather unfavorable. This was due to his musical instrument, a French horn. "Those old instruments had to be polished every week with a revolting metal polish," he says: "That was more something for friends of corrosion." The materials scientist clearly falls into the camp of corrosion haters.

At 16, he passed the entrance examination to the Wuppertal Music Conservatory. This was primarily thanks to a committed music teacher. A life as a professional musician between Brahms, Beethoven and Wagner seemed mapped out for him. "In the afternoons after school I went to Wuppertal," explains Raabe. He enjoyed the very personalized lessons at the Conservatory. He diligently practiced the double bass, which had now become his main instrument, and the French horn. But he increasingly lost interest in school: "I no longer wanted to complete my school-leaving examination." But then crisis struck.

FROM BRAHMS AND BEETHOVEN TO METAL PHYSICS

Dierk Raabe tormented himself with thoughts about whether he had made the wrong decision for his life. His early professional training as a musician made it clear to him that the rest of his life would revolve around "two, three instruments." "I have to be careful how I say this, because I don't wish to step on any artist's toes," he says, "but that was a little bit too one-sided for my taste." So he took his school-leaving examination. He had early contact with the topic of steel through his father and his uncle, who worked at Krupp. His family's background was one of the reasons he studied metallurgy and metal physics at RWTH Aachen University. "I was interested in the subject because it is at the interface between the engineering sciences and the natural sciences," explains Raabe, "because the courses included chemistry and physics."

This was obviously the right decision, because his research area is anything but one-sided. It's true that almost everything revolves around metallic materials, but they are everywhere; they shape our environment like hardly any other material. "It is a very old field, dating back to the Bronze Age," he stresses, "and today it is one of the backbones of our industrial society." Accordingly, our conversation develops into a gallop through our technical culture. In the hours that follow, the conversation touches on high-temperature materials for power plant turbines, high-strength steels for car bodies, special alloys for aircraft undercarriages, hip joint implants, gold contacts in electronic chips and corrosion-resistant components for seawater desalination plants. >

Photo: Frank Vinken

top | Complete insight: Dierk Raabe looks into the sample chamber of the new atom probe. This instrument can decipher the structure of the tiny crystals in metallic materials atom by atom.

bottom | The ultra-fine sample tips are kept in the ultra-high vacuum chamber (center of picture). The flange-mounted vacuum tube (foreground, right) contains a pole with which the researchers can move the samples into the large analysis chamber (background), where pulses of laser light or high electric voltages remove the sample tip atom by atom. An electric field accelerates these electrically charged atoms (ions) to a large area detector. The time-of-flight to the detector reveals the type of atom, and the impact location shows its original position in the crystal.

It is quickly becoming apparent that Raabe shares a love of one particular word with Mr. Spock from the science fiction series Star Trek: "Fascinating!" Otherwise, he has little in common with the cool, reserved space traveler with the pointy ears. Words just come gushing out in a slight Rhenish accent. He repeatedly jumps up from the table, rapidly sketches something on the board, then seats himself opposite his guest again. He expects his discussion partners to have the ability to take in a maximum of information in a minimum of time, of course. Boredom does not set in, at any rate.

IT'S AMAZING THAT WE GET BACK OUT OF IT ALIVE

But Raabe issued a reminder very early on, saying "you have to recognize the central thread." This concern is unwarranted. Each of the many examples makes it clear that the focus is always on the complex inner life of metallic alloys. Science has by no means reached the stage of completely understanding the microscopic behavior of these mixtures of iron, nickel, carbon, cobalt, titanium, chrome, aluminum and other ingredients from the elemental supermarket of the periodic system. This is why industry still has to work painstakingly and empirically to develop structural materials to meet new mechanical requirements or withstand extreme temperatures.

So the search for new materials is still all about intelligent trials based on experience. If there was a sound theory, materials scientists could proceed in a much more focused manner and would be more open to new discoveries at the same time. "There is no such theory for the development of new alloys," says Raabe, thus already introducing the dream goal of his research: "I can only design really new materials for a specific purpose when I, as a scientist, understand precisely what happens there."

These connections and the properties of materials never cease to amaze him. He is already talking about materials that most of us would trust with our lives without giving it a further thought. "Take an airplane," says Raabe enthusiastically: "I'm always amazed to get back out of it alive!" He uses his hands to illustrate how the pressurized cabin made from an aluminum-copper alloy expands its diameter by almost 20 centimeters in the thin air at altitude: "Did you know that?" Then he moves on to the turbine vanes, which are located directly behind the combustion chamber of the aircraft's engines and reach scorching temperatures of up to one thousand degrees Celsius. "We can only go down on bended knee and thank our maker that they don't fly out the back in bits and pieces," says the researcher with a laugh.

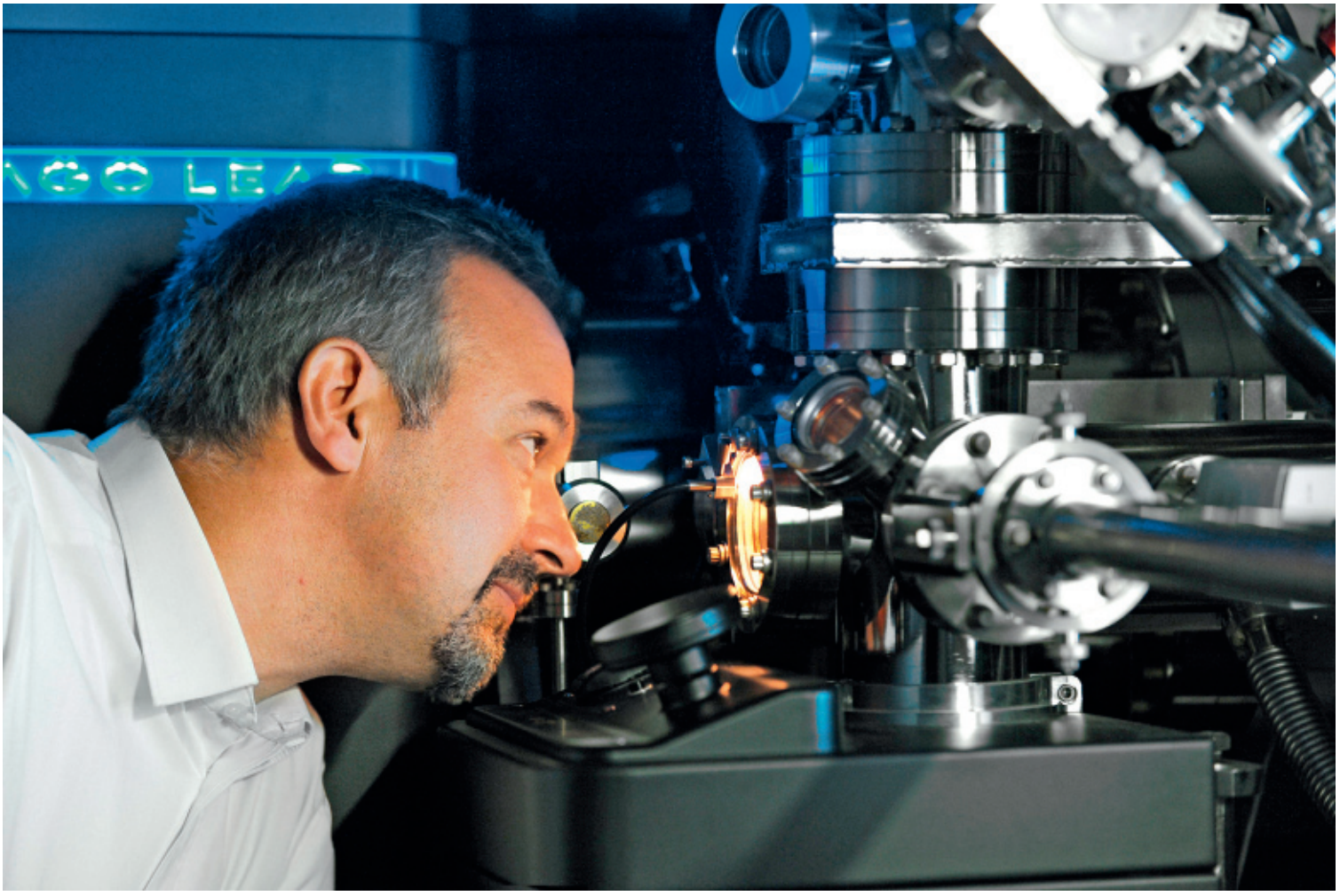
Of course he knows very well why this doesn't happen. But he wants to have an in-depth understanding of the mechanical behavior of such materials. And this is where quantum mechanics comes into play, which describes the behavior of individual atoms and electrons. The engineer-to-be first came into contact with this fundamental but difficult to understand theory as a student via a good physics lecture. It has now become a workhorse for him, thanks to the intense collaboration with his fellow Director Jörg Neugebauer and his theory group. It is unusual to learn about the fundamentals of quantum mechanics when studying materials science because the field is close to mechanical engineering at most universities. And if you want to develop materials for large technical components, you traditionally don't need to worry about individual atoms and electrons.

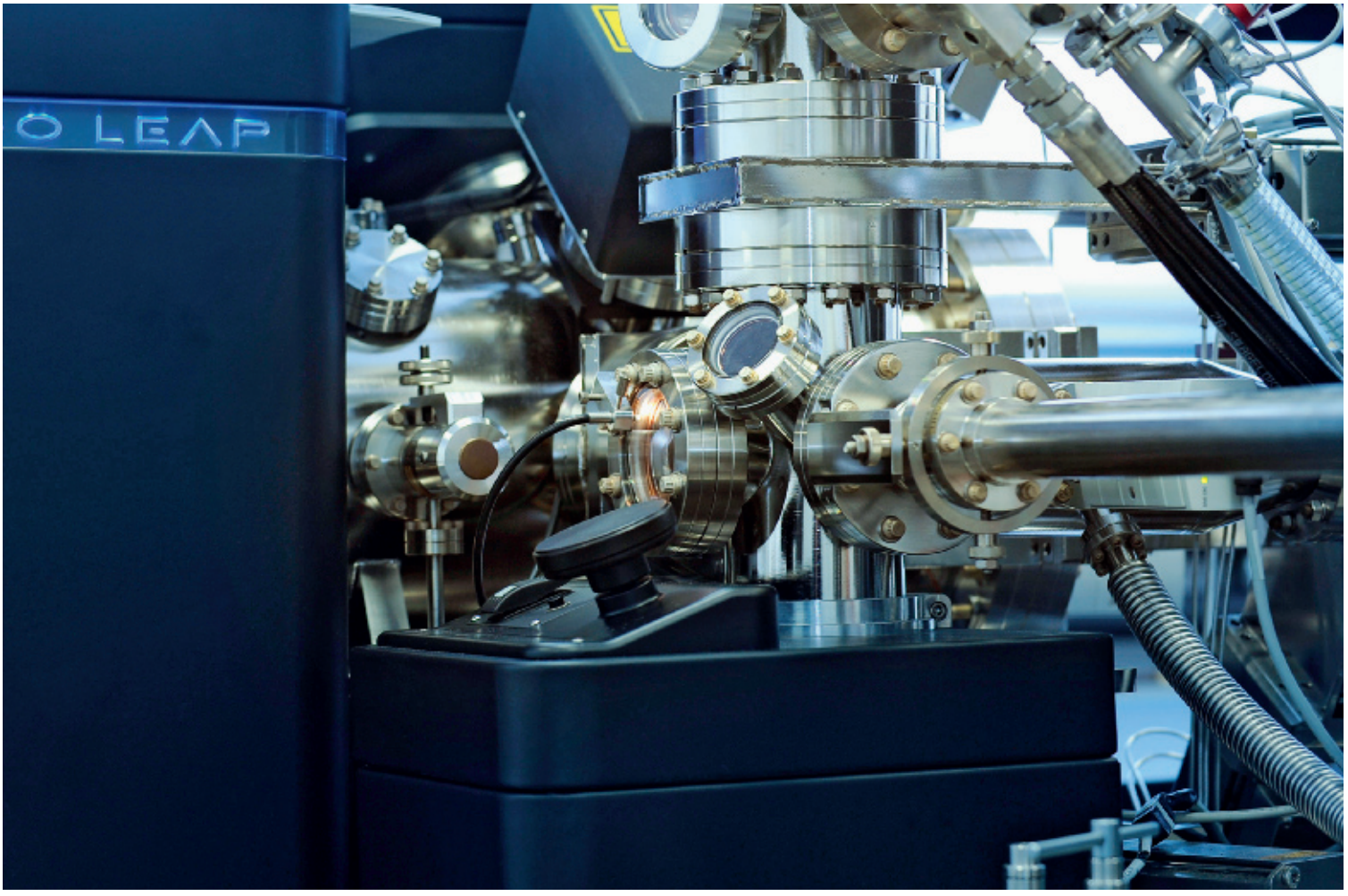
QUANTUM THEORY BECOMES A WORKHORSE

But Dierk Raabe and his colleagues at the institute want to radically change this attitude. If Raabe's dream comes true, the same will happen to mechanical engineers as happened some time ago to electrical engineers: they had to get used to quantum mechanical design tools about sixty years ago after the invention of the transistor. "We want our long-term research work to contribute to materials being developed completely on the basis of quantum mechanics within 15 years or so," says Raabe: "I absolutely believe in this vision!"

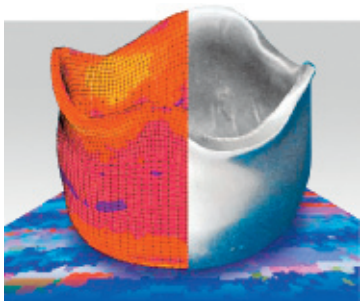
Very early on in his scientific career, Raabe was already developing computer simulations that could be used to theoretically predict the properties of materials. This has been his main field of research since obtaining his doctorate in Aachen in 1992. At that time, he was heading a group at the Institute for Metallurgy and Metal Physics. The German Research Foundation rewarded his excellent findings

Photo: Frank Vinken (2)




LEAP

» We want our long-term research work to contribute to materials being developed completely on the basis of quantum mechanics within 15 years or so. I absolutely believe in this vision!



The metal does not flow uniformly everywhere in the press like viscous honey, but moves in preferred directions. This critical "earing" can be realistically simulated by the software developed by Raabe's team (left).

with a prestigious Heisenberg fellowship. In 1997, after gaining his postdoctoral lecturing qualification, he used the fellowship to go to the US. He carried out research at Carnegie Mellon University in Pittsburgh and at the High Magnetic Field Laboratory in Tallahassee, Florida. The Max Planck Society was so impressed by Raabe's innovative methods that, in 1999, at just 34 years of age, he was appointed to the Max Planck Institute for Iron Research as one of the youngest Max Planck Directors.

"My advantage was maybe that I sit between engineering sciences and natural sciences and have done a lot of simulations," he continues. But one should not think that these complex simulation programs merely ask for a couple of desired material properties to be entered into a template and the computer then spits out the recipe for a new alloy. The simulation programs in materials design are very complex. Many simulations do simplify the metals in one crucial aspect, though: they ignore the complicated microstructure – just as ship designers do not care about individual water molecules. "This is called homogenization," explains Raabe.

Such simplifications are justified in many applications. In reality, however, metals and metallic alloys are grainy in a complicated way. They consist of many small crystals of between a few micrometers (thousandths of a millimeter) and several millimeters in size, depending on the material. The atoms in these small crystals have a very regular arrangement, like that of diamonds or quartz. The situation for alloys is even more complicated, because the atomic composition can vary from crystal to crystal.

However, the interaction of these crystal grains determines important material properties. So what can sometimes happen is that sheet metal acquires unsightly lugs after being cold formed into a fender, for example. The metal does not flow uniformly everywhere in the press like viscous honey, but prefers certain directions. This is due to the small crystals. Their stacked atomic layers mean that they give in a preferred direction – like sandwiches, whose slices of bread prefer to slide parallel to each other on the slippery filling.

AUDI AND MERCEDES USE THE SIMULATION PROGRAM

This is a growing problem for the automotive industry with its tendency to use folded car body parts with ever more complicated designs. So some years ago, Raabe and his team developed a simulation program that is now used by vehicle manufacturers like Audi and Mercedes. They use it to predict the behavior of different steel grades in the presses. This saves on expensive tests and high scrap rates when starting up production lines for a new model.

The researchers in Düsseldorf have found a clever way of translating the behavior of the small crystals into the forming behavior of complete workpieces in their simulation program. If the computer had to simulate the interaction of many millions of virtual crystals, grain by grain, it would

Graphic: MPI for Iron Research

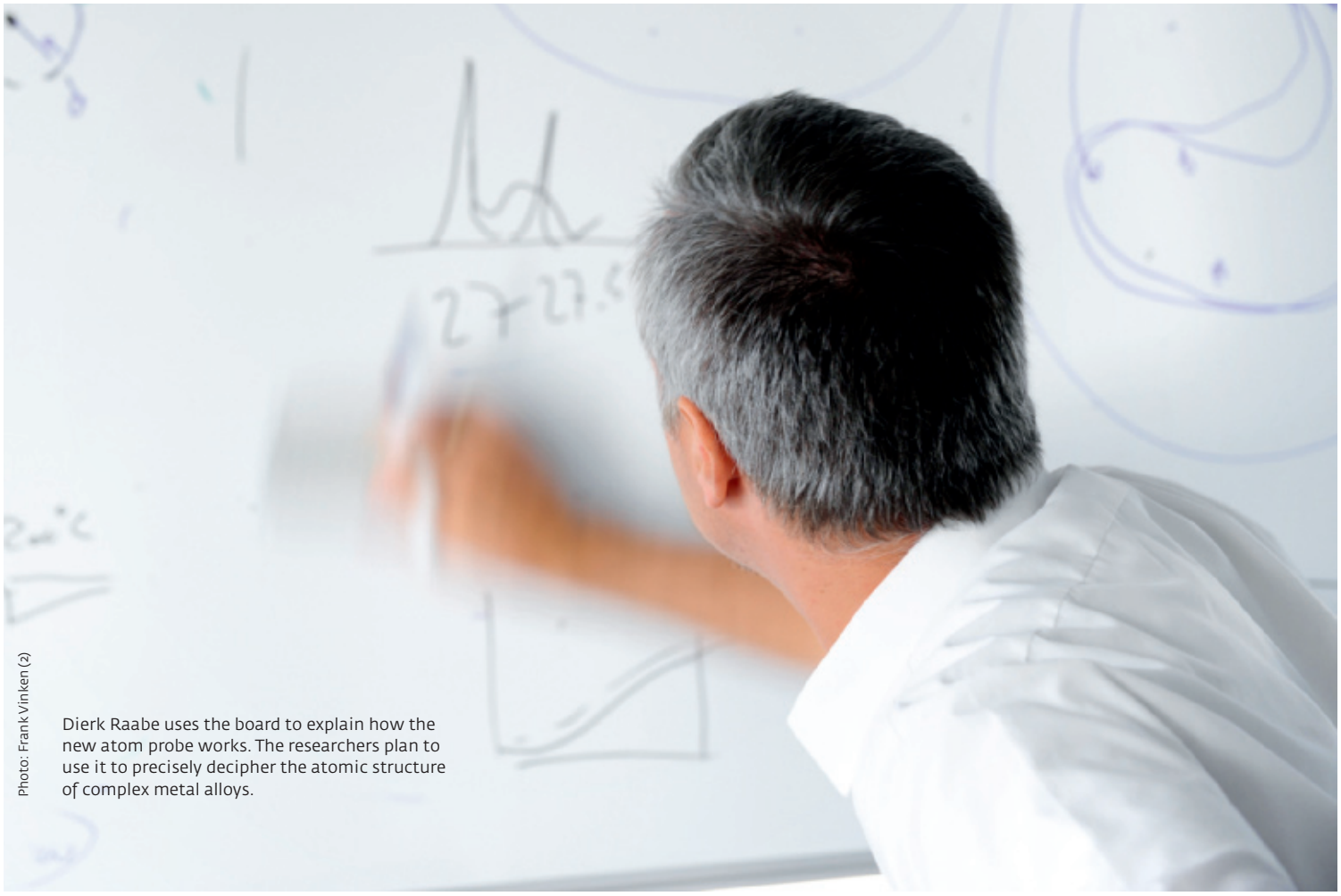
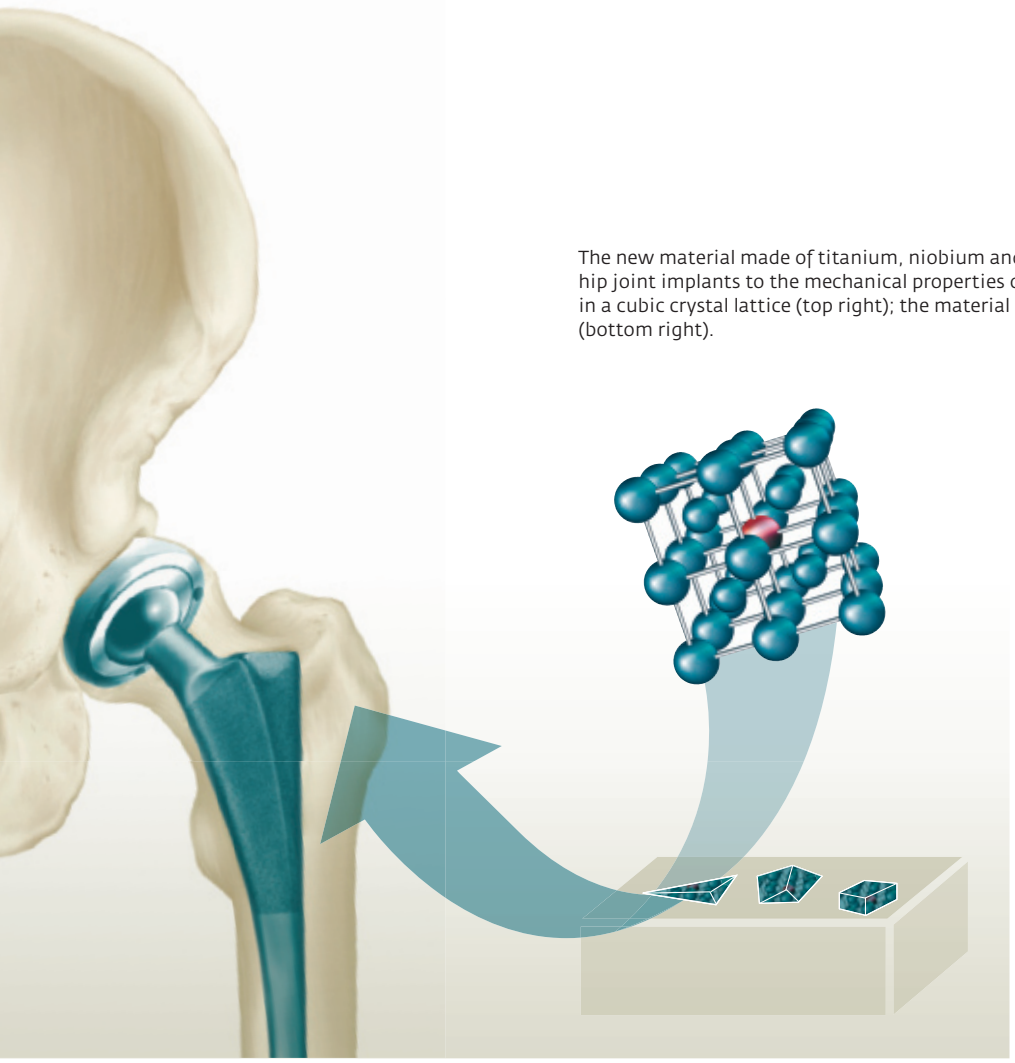


Photo: Frank Vinken (2)

Dierk Raabe uses the board to explain how the new atom probe works. The researchers plan to use it to precisely decipher the atomic structure of complex metal alloys.



The new material made of titanium, niobium and zirconium is better at matching hip joint implants to the mechanical properties of bone. The atoms are arranged in a cubic crystal lattice (top right); the material consists of many such small crystals (bottom right).

take too long. Raabe's team thus had the idea of mathematically grouping all crystals that have the same orientation, because they exhibit the same flow behavior. This shortened the computing time by a factor of one hundred.

THE MULTI-SCALE PROBLEM

It's not just the different orders of magnitude – from the atom to micrometer-sized crystals to meter-sized workpieces – that result in a complicated "multi-scale problem," as Raabe calls it. Even more extreme is the spread of the time scales in which a workpiece corrodes or succumbs to permanent stress as a result of creeping: they range from electron movements within femtoseconds (trillionths of a second) up to years.

"These scales cannot be bridged with computer simulations, not even in 30 years," says Raabe: "So we have to bridge them theoretically." A discovery comes to their aid: the exact quantum mechanical description of what happens on the microscopic scale between a few atoms in the small crystals can already provide good answers. One example is provided by the mechanical properties of the material. "The first work in this field carried out in collaboration with colleagues from the theory side resulted in a precision in predicting certain phenomena that really surprised me," says Raabe. His fellow Director Jörg Neugebauer's team studies the very demanding application of quantum theory. The collaboration works very well: "We are dreaming pretty much the same scientific dreams," comments Raabe.

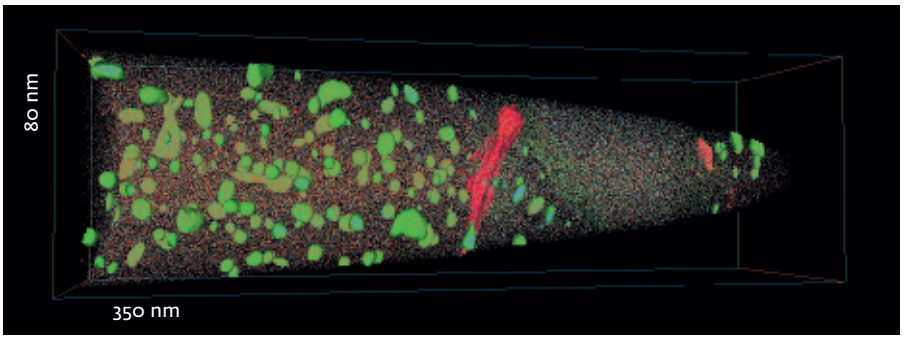
In quantum mechanical materials design, the focus is on the electrons. They form the adhesive that glues the atoms together. Quantum mechanics can describe these adhesive forces very precisely on the atomic scale. The equations can be used to directly derive how the crystal is going to behave mechanically, for example. Although a large, "macroscopic" workpiece consists of many crystals, it is these that determine the limits of the material properties – just as a chain can only be as strong as its individual links.

"My dream is to achieve the electronic design of materials," adds Raabe. Compared to empirical development methods, this elementary theoretical approach has one great strength: it makes it possible to develop completely new materials. Empiricism, on the other hand, can only vary things that are already known.

BRAND NEW TITANIUM ALLOY FOR HIP IMPLANTS

Dierk Raabe wants to convince mechanical engineers and traditionally minded materials scientists of the possibilities of the quantum mechanical approach. He hopes that some impressive demonstration projects will help. One is a brand new titanium alloy for hip implants. "About a million people worldwide receive this type of artificial hip annually," explains Raabe. Unfortunately, these new joints loosen after a few years and have to be replaced. The problem is the bone, which recedes. Titanium is more than five times as rigid as bone, so the metal joint takes much more strain. Just like a muscle that is no longer trained, a bone that has too few demands put on it grows weaker as a result.

Illustration: dpa Picture-Alliance (left); Christoph Schneider (right)



Dierk Raabe in front of the powerful computer system that evaluates the data from the atom probe. From the measurement data, it must calculate the types and the crystal positions of between 10 and 100 million atoms per analysis. The graphs generated show the greatly enlarged internal atomic structure of a superfine sample as thin as the tip of a needle in an atom probe, for example. This instrument can detect the positions of the different atoms (different colors) of an alloy in the atomic crystal lattice.

The Düsseldorf-based researchers have succeeded in developing a much softer titanium alloy. Mechanically, it adjusts much better to the bone because it has a different crystal structure than titanium. The development of this brand new material, consisting of biocompatible titanium, niobium and zirconium, would not have been possible without quantum mechanics. The group is already negotiating with manufacturers of such prostheses.

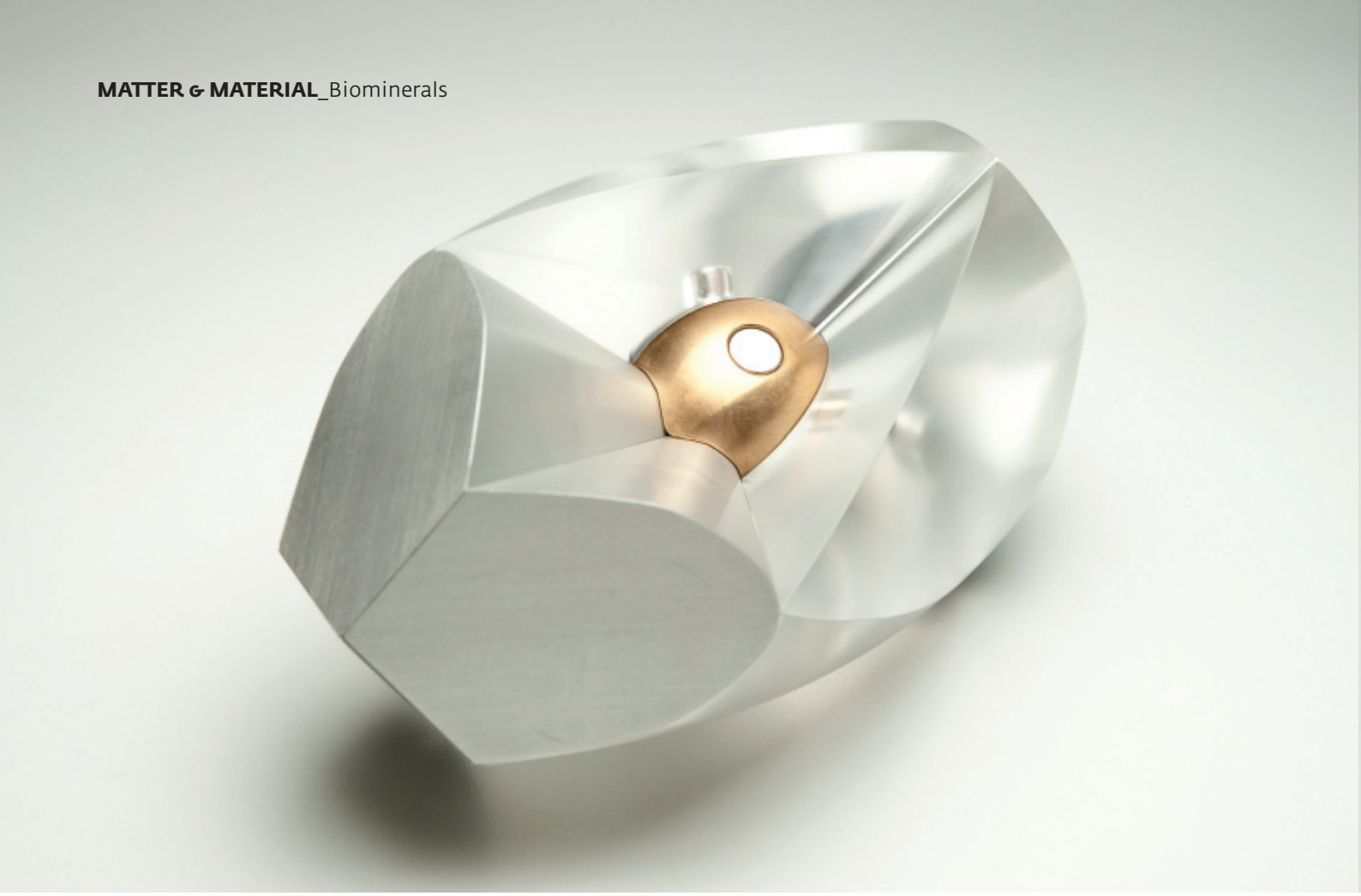
The social relevance of his research is very important to Raabe. But the researchers also hit upon titanium alloys because they are still relatively simple to describe on an atomic level. "So, in many ways, it was a strategic decision," says Raabe. He is already dreaming of making high-temperature materials with a much more complex structure even more heat resistant. These are mixtures of more than a dozen different chemical elements. The huge turbines in modern coal-fired power stations give him a reason: if they could increase their operating temperature "from about 580 to 720 degrees Celsius," explains Raabe, they would convert coal into energy much more efficiently and emit considerably less carbon dioxide into the air. "For one kilowatt-hour of electric power, I would then no longer need to shovel in half a kilogram of coal," says Raabe: "It could be less than a third of a kilogram!"

Four years ago, the German Research Foundation awarded Raabe the Gottfried Wilhelm Leibniz Prize. This carries the highest prize money of all German science prizes and increased his research budget by 1.55 million euros. He has now used this money to buy an instrument called an atom probe. It uses a thin sample of material to detect precisely where in the crystal structure the different atoms are located. Raabe hopes to use this data to make even high-temperature steels accessible for quantum mechanical calculations.

When Raabe talks about his many projects, partnerships and contacts with other researchers, the passionate communicator and networker shows through. Did he learn this during his time as an orchestra musician? After a brief pause, he confirms that there was a link with science: artists are also pronounced individualists, but they still have to come together to form a common harmony.

The creativity that studying music imparts is also important to him – but he hardly ever gets to play music now. "The atmosphere at our institute is so good," he laughs "that I prefer to keep myself busy at home with a scientific subject rather than play music." ◂

Photos: Frank Vinken (top); MPI for Iron Research (bottom)



Balance Built on Dust

Whether bones, teeth, or mother-of-pearl – evolution has always found ways to invent suitable materials for every task. This is also evidenced by otoconia: tiny crystals found in the inner ear, whose structure, formation and function are being investigated by **Rüdiger Kniep**, Director at the **Max Planck Institute for Chemical Physics of Solids** in Dresden. Kniep's research may also help in finding a treatment for balance disorders.

TEXT **TIM SCHRÖDER**

Model of a particle of ear dust (otoconium). It consists of a belly (sphere) and a total of six branches on which additional material is later deposited (below).

Photo: Bastian Ehl (2)

Rüdiger Kniep stumbled on otoconia through one of those very rare coincidences. In 1985, an ear, nose and throat (ENT) doctor knocked on the door of his laboratory in Düsseldorf and placed a small glass container on the table in front of Kniep. It held a small quantity of ear dust, or otoconia, particles of just a few micrometers in size that originated from the inner ear of a guinea pig. Kniep had never heard of the substance. He is a solid-state chemist and researches how atoms link to each other and how new types of crystals form. Kniep studies basic chemical processes – an area that is far removed from the mammalian inner ear organ.

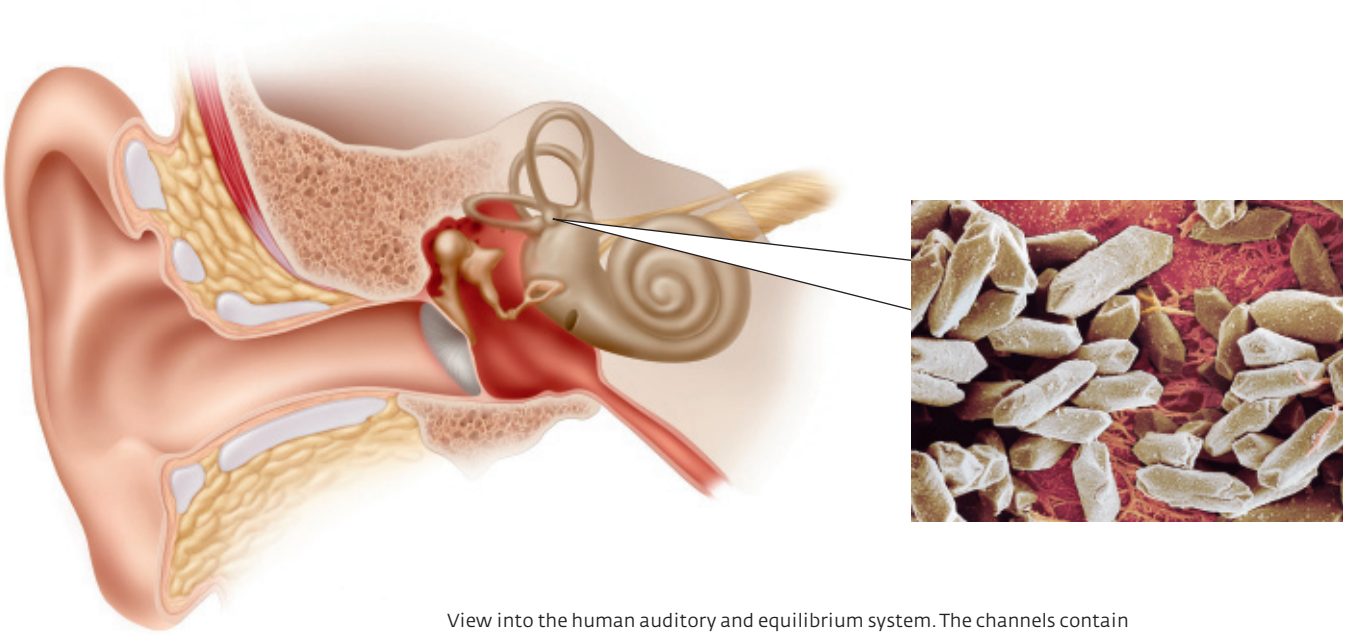
But Kniep had something that was found in only a few laboratories at the time: a scanning electron microscope – a man-sized device that can scan minute objects with an electron beam, making minute structures visible, like the surface of a crystal or bristles on an ant leg. The ENT specialist wanted to use the microscope to image and decipher otoconia, how they are structured and how they work. Kniep agreed to help. His assistant made several dozen images with the microscope; under normal circumstances, that would have been that. However, when Kniep saw the images, he was bowled over: the specks, no bigger than dust particles, turned out to be perfect geometrical bodies – fat little grains of rice whose tips are flattened on three sides.

BIOMINERALS ARE ALSO FOUND IN TEETH AND BONES

Perfect crystals usually grow in rocks or in test tubes. Sugar and salt form crystals and are usually bounded by flat surfaces. Otoconia, however, are both barrel-shaped and bounded by flat surfaces at their tips. This unusual phenomenon is born in the ear.

For an entire year, Kniep brooded over how the organism manages to grow otoconia. How do the biological minerals in the body take on their characteristic forms? He thought about the internal structure, pored over the images for hours, made sketches and, in the end, put the file away in a closet without having reached any conclusions. Everyday life at the laboratory had to go on. Semiconductor materials were a key topic at the time, and no less fascinating than otoconia.

The otoconia file would probably have lain dormant in the archive forever had not another coincidence arisen in summer 2006: Rüdiger Kniep had been researching not only the characteristics of metallic conducting or semiconducting materials for a long time, he had also embarked on the study of biominerals, the hard natural substances from which teeth and bones grow. He had experimented with apatite, in particular, a material that can be found in rocks as well as in bones and teeth. The material consists mainly of calcium and phosphate. When apatite is used in teeth, it is combined with a lit-



View into the human auditory and equilibrium system. The channels contain the sense of balance in the three directions in space. The otoconia, shown on the right in a scanning electron microscope image, are located at their base.

tle collagen – large protein molecules that act as a structural framework to which the apatite attaches. These organic-mineral compounds are known as composites.

BARREL-SHAPED RICE GRAINS WITH FLATTENED TIPS

Rüdiger Kniep actually succeeded in creating artificial dental enamel and in developing a kind of tooth repair kit from it. However, he was not satisfied with this, as the apatite in the tooth also contains carbonate. Thus, to obtain apatite that is completely true to its natural state, he considered it necessary to add a pinch of carbonate to the experiment. He then allowed calcium, phosphate, carbonate and other agents to flow through gelatin, which is made up exclusively of collagen, for several days. When he finally examined the resulting solids, he couldn't believe his eyes: the test equipment contained not only apatite, but also tiny calcium carbonate crystals. Moreover, their form seemed very familiar to him: barrel-shaped rice grains with flattened tips – a clear case of déjà vu. Twenty-one years after the visit from the ENT doctor, artificial otoconia had been produced in a laboratory experiment – just as perfectly formed and beautiful as their naturally occurring cousins. Kniep was electrified.

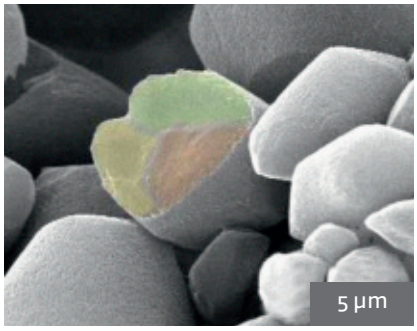
The scientist resurrected the old file and reopened the otoconia chapter; he wanted to establish definitively what he was dealing with here. The constituent elements were now clear, but not much more. Kniep worked his way through the literature. The result was astonishing. Hardly any work had been done on the topic in the intervening 20 years. "It was known where otoconia could be found and what they looked like, and a vague idea of their ingredients and function existed, but that was all," says Kniep.

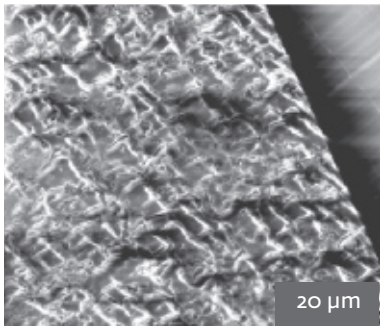
It had long been known that otoconia are found in the labyrinth in the inner ear, the organ of balance in mammals and humans. In terms of form, the labyrinth is akin to an abstract tuba with multiple coils. The otoconia rest on a kind of gel cushion in the maculae, two fluid-filled chambers that measure just a few millimeters in size. Minute tethers known as fibrils hold the otoconia in place on the cushion. Fine sensory hairs protrude into the space below, which is separated by a thin layer. It was already known that otoconia work as acceleration sensors – as tiny masses that change their position when the head and body move. They transmit this movement to the sensory hairs. Precisely how these micrometer-sized specks, otoconia or "ear dust" grow, or how exactly they work, remained an open question.

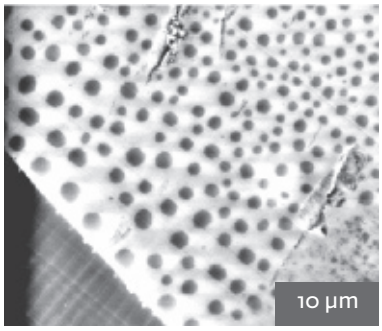
Kniep thus set to work investigating the ear dust. First, he observed artificial otoconia growing in the laboratory. Kniep has been a Director at the Max Planck Institute for Chemical Physics of Solids in Dresden since 1998. His biomineral laboratory is clean, manageable and above all cost-efficient, he says. Neither the laboratory equipment nor the agents used there are particularly expensive – calcium, phosphate, carbonate and fluoride are all run-of-the-mill chemicals. As the collagen component, the scientist uses gelatin, which he dissolves in water.

One of the most important instruments found in the laboratory is the U-shaped tube in which Kniep and his colleagues grow the composites. It consists of two L-shaped glass legs that are fitted together to form a U-shaped container. The gelatin gel sits in the middle. The chemists fill the two "legs" of the container with solutions of chemicals whose constituents diffuse into the gel and react to form the

Illustration: Photoresearchers; photo: SPL – Agentur Focus







above | The fractured surface of a guinea pig otoconium (left); the surface corresponds to three of the branches in the early stage of development (see diagram on page 73), on which additional material is deposited. The belly of an artificial otoconium can absorb fluid through its porous surface and acts like a rubber ring (right). In contrast, the more dense structure at the ends gives them greater weight (center). All images were produced in a scanning electron microscope.

below | Annu Thomas with a U-shaped tube. The middle of the tube contains a gel comprising gelatin into which ions from the two solutions, left and right, diffuse. This enables the doctoral student to observe how artificial otoconia grow.

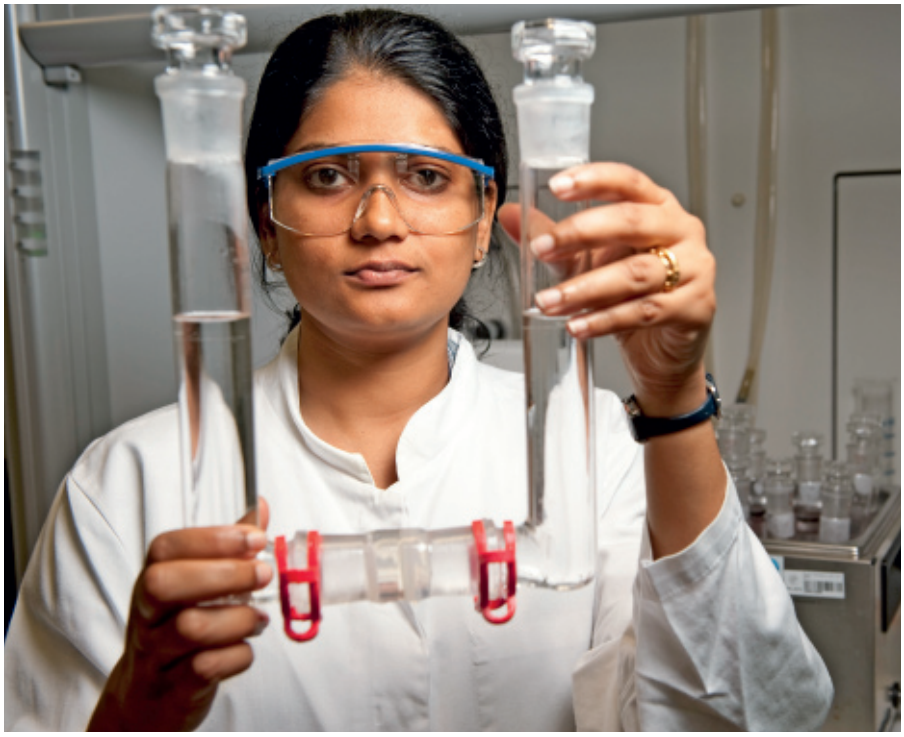
solids. Kniep's first otoconia were produced in this way and their successors were also grown in a very similar way. The detailed study of otoconia, however, is a more costly process due to the sophisticated analytical equipment required.

DECODING THE GROWTH PROCESS IN THE LABORATORY

In order to analyze the individual stages of growth, Kniep stopped the crystal formation at different stages. He then placed the tiny specks under the electron microscope. What he saw there was also rather surprising. The otoconia from the U-shaped tube grow in different directions at different speeds. First, six branches grow from a central point that all touch in the middle at their tips. Sets of three branches then align themselves with each end of the structure. A belly then develops around the middle, growing more slowly than the branches.

Although the artificial nature-inspired biomimetic otoconia are somewhat larger than the natural biogenic ones, they also grow within a matter of a few days. "Natural otoconia reach their full size around seven days after birth," says Kniep. No new formations or growth changes occur after this. This indicated to Kniep that his artificial calcite grains could be fully comparable to the natural model, and that the insights gained in the chemistry laboratory could ultimately be applied to nature.

Kniep is a basic researcher and freely admits that outsiders typically don't find his research on solid-state chemistry particularly fascinating. Chalcogenides – metal compounds comprising oxygen, sulfur, selenium, and tellurium – nitrides and other com-



Photos: MPI for Chemical Physics of Solids (top, 3); Bastian Ehl (bottom)

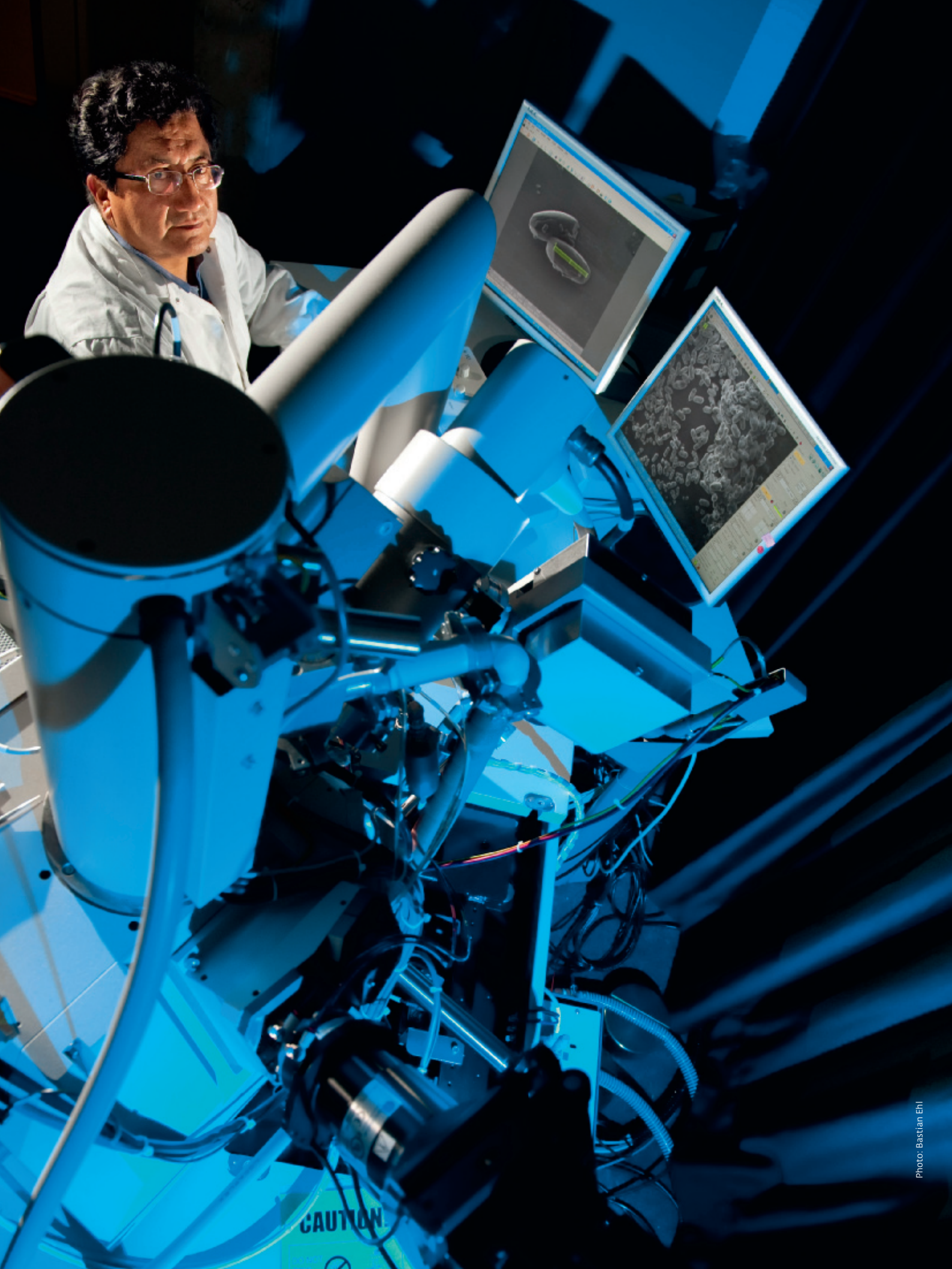
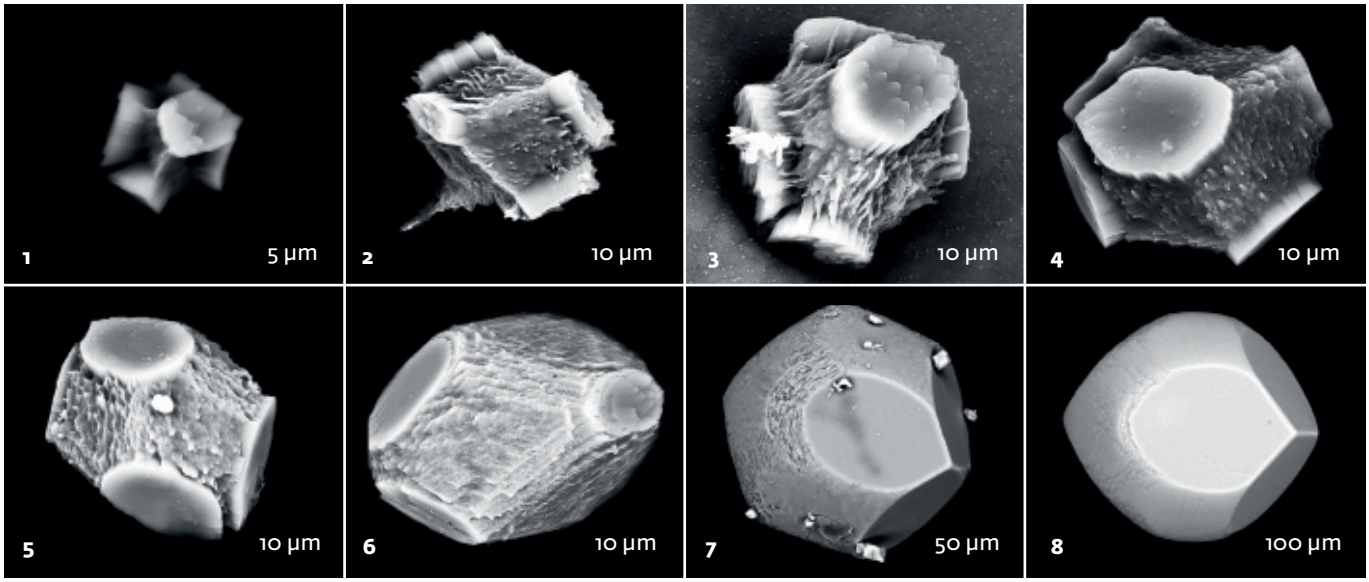


Photo: Bastian Ehl



above | Growth in slow motion: Starting from the earliest stage with six trumpet-like extensions (only partly visible, image 1) otoconia grow to their final form within a few days (image 8). They then exhibit three smooth faces at each end and a curved belly surface.

left | Tiny structures under the microscope: Wilder Carillow examines the ear stones with the help of a focused ion beam microscope.

pounds, and the growth conditions and characteristics of crystalline materials, are far removed from everyday life. This is not the case with biominerals. "In the apatite-gelatin system, I deliberately sought out a topic that is closely related to humans: the formation of bones and teeth. It's fascinating. It's my hobby," says Kniep. "I hope to achieve something here that will be of direct benefit to mankind."

NUTRITION DETERMINES TOOTH COMPOSITION

It was actually Kniep's undergraduate mineralogy professor who unwittingly pointed him in the direction of biominerals, long before the topic had attained any major scientific significance. "When I did my diploma examination in 1971, my professor asked me for a reason that might explain why our teeth are made of the mineral apatite and not quartz, which is much harder," explains Kniep. "At the time I muttered something about the pH value and acid in the mouth."

There is, of course, a plausible explanation for this. People constantly ingest calcium and phosphate, the constituent elements of apatite, in their food. The same is true of carbonate, the building block of calcite. Quartz, on the other hand, consists of silicon dioxide, or sand, which rarely enters the human mouth in dissolved form. Therefore, it makes sense for the organism to synthesize apatite and not quartz. "It is clear that nature does nothing without good reason. The choice of building materials and the shape of teeth and otoconia are the result of millions of years of evolutionary optimization processes. And we are trying to find out where the advantage lies," says Kniep.

After the growth experiments in the laboratory had revealed that otoconia consist of two different structures – the belly and the six branches whose tips align to form three planar faces at each end – Kniep delved deeper into their structure. He cut the grains at the transition between the belly and the rhombohedra at the tips of the otoconia. The electron microscope image revealed that this was the correct approach to adopt, as the belly and the rhombohedra have completely different fine structures.

THE POROUS BELLY ACTS AS A RUBBER RING

The belly of an otoconium is porous and the collagen fibers within it are rather disorganized in structure. In contrast, the rhombohedra that form from the initial branches at the tips are densely permeated by parallel-oriented biomolecules that break through the smooth surfaces at right angles. Kniep suspected he knew the reason for this: the porous belly probably absorbs macular fluid – endolymph – and acts as a kind of rubber ring. The dense and massive rhombohedra at both ends of the rice grain, in contrast, act as pendulum weights that react to the accelerations and cause the otoconia to tilt or rotate.

Kniep thus provided an initial explanation for the different structures and densities in the belly and branch-

Photo: MPI for Chemical Physics of Solids

20,000-times larger than the original: Rüdiger Kniep holds an otoconium model.

es of the otoconia. Some time ago he simulated the nucleation of the tooth-building mineral apatite in gelatin. In this case, three protein molecules cluster to form a triple helix, an elongated triple screw. Apatite grains measuring just a few nanometers (millionths of a millimeter) then form in and at this triple screw. According to Kniep, the process involving otoconia-calcite should be very similar. However, it still remains unclear how the different areas – with the strictly ordered collagen fibers at the rhombohedral ends and the disordered fibers in the belly – arise in the laboratory.

Kniep has made significant progress toward reaching an in-depth understanding of the function of otoconia. He suspects that elongated protein molecules, molecular fibrils, grow out of the exterior shell of otoconia, in particular from the rhombohedral surfaces. They grow together with the gel cushion and act as tethers. The idea behind this is that the movement of the head and acceleration of the maculae cause the swimming otoconia to change position. Like ships tethered to a quay wall by a rope, the otoconia pull at the fibrils. This pulling force continues through the gel cushion of the maculae down to the sensory hairs, which then transmit the acceleration information via the nerve pathways to the brain.

DAMAGED OTOCONIA CAN CAUSE DIZZINESS

Kniep may now even be able to explain what happens when otoconia fail. It is known that older people are more susceptible to dizziness and that untethered otoconia go astray in the labyrinth canals. A possible reason for this is that otoconia release themselves from the fibrils and thus don't transmit the acceleration information correctly. As a result, they turn the acceleration sensor in the inner ear completely on its head. Kniep's detailed observations provide a plausible explanation for the destruction of the fibrils.

To analyze the internal structure of otoconia, he chemically dissolved the calcite framework in stages. It emerged that the porous belly disappears first. Then deep holes are gradually formed also in the smooth rhombohedral surfaces. This indicated to Kniep why otoconia relinquish their hold in advanced age: if the calcite dissolves, the holding points of the fibrils also crumble. The more the grain degenerates, the more unstable its position within the network of fibrils becomes. Experts to whom Kniep presented his hypothesis found the idea plausible. "But they doubted that the tests on the biomimetic otoconia could actually be transferred to nature," says Kniep.

The next step was obvious: a comparison with biogenic – that is, human – otoconia. Kniep asked his local ENT colleagues and they provided him with ear dust from older patients. And he scored a direct hit: the aged otoconia from the ear looked exactly the same as the decalcified artificial otoconia. Both versions had lost their bellies, and the rhombohedral branches were crisscrossed by deep furrows. Kniep believes it is possible that, with increasing age, the pH value of the en-

Photo: Bastian Ehl

» In the future, it may also be possible to regenerate the otoconial calcite by adding the necessary components, but we are still far from being able to do this today.

dolymph in the maculae changes. The degeneration process begins and the fibrils tear off.

Kniep has already developed a repair kit for dental enamel with his colleagues. It is not inconceivable that he will succeed in developing something similar for otoconia in cooperation with ENT specialists. "In the future, it may also be possible to regenerate the otoconial calcite by adding the necessary components, but we are still far from being able to do this today," says Kniep.

ADDING SUGAR PRODUCES SLIMMER GRAINS

One reason for his hesitancy here is that the otoconia produced in the U-shaped tube are not yet entirely identical to the real biogenic grains. The latter are somewhat more elongated. "It has been suspected for some time that sugar components are also incorporated in the biogenic calcite. So we imitated this in the laboratory." Sure enough, when the researchers filled the U-shaped tube with agarose or other sugars in addition to the gelatin, slimmer otoconia formed in the gel. Kniep's colleagues are currently testing a range of recipes in which they use different molecules and vary the concentrations of the ingredients.

How natural the artificial otoconia are is one of the questions currently preoccupying Kniep. "Pretty close to the natural version, actually" would be the answer, as both versions share a second astonishing characteristic. In inanimate nature, normal crystals, like quartz, grow as a result of the congregation of atoms to form a regular atomic lattice that constantly increases in size. Scientists refer to crystals of this kind as single crystals. If these crystals are irradiated with X-ray light, it is possible, from the diffraction pattern, to identify whether they actually consist of a single crystal.

Real otoconia also appear as single crystals in X-ray light. However, they are not single crystals in the classic sense – they are permeated by molecular fibers and consist of many individual calcite blocks that are just a few nanometers in size. There is thus no question of them being single crystals. And yet, the diffraction pattern of the single crystal is clearly visible in X-ray light. "Living organisms have the fascinating ability to form nanostructured composites that behave like single crystals," says Kniep. In fact, nature is not the only system that can do this: the otoconia from Kniep's U-shaped tube behave in exactly the same way under X-ray light.

Kniep is actually very close to the natural model. He is currently trying to establish how the growth of the wondrously symmetrical otoconia begins, and is seeking the nucleus of the rhombohedra. In the meantime, Kniep is working in cooperation with the ENT specialists at the ORL University Clinic in Dresden. Its Director, Thomas Zahnert, hopes that it will be possible to use the knowledge gained about the growth of otoconia for treatment purposes at some stage in the future. "We are still very far from this, but it is conceivable that it will be possible to use biomimetic otoconia as a kind of replacement organ in the future." Until then, the researchers will have to reach an even better understanding of otoconial synthesis and the function of the grains. And who knows – the leap into reality may not be so far off after all. ◂

GLOSSARY

Rhombohedron
A polyhedron that is formed exclusively by rhombuses. Opposing sides and angles in rhombuses are equal in length and size.

Macula organs
Structures in the inner ear that measure linear acceleration in space. The sacculus records vertical acceleration and the utriculus records horizontal acceleration.

Collagen
A very pull-resistant and almost inelastic animal protein that forms the main component of bones, teeth, and cartilage. In terms of weight, it accounts for one third of the total protein in the human body.

Apatite
A mineral consisting of calcium, phosphate and another component (fluoride, chloride or hydroxide).

Calcite
A crystalline form of calcium carbonate (chalk).

Soil researchers setting out to work: New director Susan Trumbore (far right), group head Markus Reichstein (in the orange pullover) and his colleagues from the Max Planck Institute for Biogeochemistry set out to obtain soil samples for later analysis in the laboratory.

Photo: Sven Döring

Climate Buried **in the Soil**

The role of soil has been largely neglected in climate models to date, but this is set to change. Scientists working with **Markus Reichstein** at the **Max Planck Institute for Biogeochemistry** in Jena are studying the climate-relevant processes that take place below ground and are developing models to describe them.

TEXT **CORNELIA REICHERT**

The Earth is a living, self-regulating super-organism. When British geochemist James Lovelock presented this concept of the Earth in his Gaia theory in the 1970s, he attracted much praise and much criticism: theologians, esoterics and those seeking meaning welcomed the new holistic perspective. Science, however, rejected the theory and condemned, in particular, Lovelock's lax use of the concept "life" – after all, the Earth cannot reproduce. But with the intensification of climate research, it has become increasingly clear that the only approach that can work here is a systemic one – the idea of the Earth as a holistic system.

Researchers agree that polar ice, the oceans, the atmosphere and forests are the main protagonists of the global climate system. But what about the soil? It is largely ignored in the standard model calculations, such as those on which the current IPCC World Climate Report of 2007 is based. However, questions such as how the biogeochemical processes below ground react to the fact that the climate is changing and, conversely, how the processes below ground influence the climate must also be explored.

"As a factor in the Earth system, soil is the poor cousin when it comes to research, and we would like to remedy this," says Markus Reichstein, who heads a research group at the Max Planck Institute for Biogeochemistry in Jena. "I believe that soil has thus far been significantly underestimated as a climate factor."

"A RISING STAR IN THE FIELD OF ECOLOGY"

Since his student days, Markus Reichstein's main focus has been the world beneath his feet. He studied landscape ecology at the University of Münster and researched humus in the mountain soils of Davos, Switzerland for his degree. Today, he also seeks to understand the processes that take place below ground through theoretical approaches. Since 2006, the junior researcher and his team have been developing possible models for the role of soil in the climate system. >

Photo: Sven Döring

Their work is highly regarded throughout the world. For example, the journal Science Watch from the Institute for Science Information (ISI) in Philadelphia regularly publishes statistics on who is leading the science race. On its website, Reichstein has been dubbed a "rising star in the field of environmental science and ecology."

THE TOOLS: MATHEMATICS AND A CORE SAMPLER

"The art of modeling consists in abstracting the real world and creating a link to the world of mathematical formulas," says Markus Reichstein. Mathematics is an important tool here, but no more than that: "I remember, for instance, a mathematician who started a doctorate at the same time as I did. He was excellent at his subject, but he had enormous difficulties in reconciling the real world with mathematics." To do this, the gap between the sciences must be bridged, and this is precisely what Reichstein and his colleagues do: they use field and laboratory experiments to test how well or poorly their theoretical hypotheses describe reality.

"To be able to even consider how the soil could be described in terms of mathematical formulas, one must first understand what the soil actually is and just what goes on within it," says Reichstein. The soil forms the intermediate world between the surface of the Earth's rocky crust on the one hand, and the vegetation cover and air on the other.

The soil comprises different layers, which experts call horizons. Below the top buffer layer lies the humus horizon, a layer of dead and decaying plant material. Beneath the humus lies the weathering layer, in which the minerals of the Earth's rocky crust are broken down and converted. Each individual layer is teeming with life: "Wherever you dig, you'll find billions of different microorganisms frolicking about in every handful of soil," says Reichstein.

The droves of bacteria, protozoa, fungi, algae, worms and insects live at different depths in the soil and in very different ways. Some of them enter into symbiosis with plants. Through their roots, the plants release carbohydrates, from which the microorganisms live. In turn, the microorganisms give nutrients back to the plants – a classic win-win situation: everyone gives, everyone takes, and everyone benefits. Some of the other tiny organisms live from plant mortality. Bacteria and protozoa, for example, get their energy by breaking up dead plant material, digesting it and consuming the carbon from it.

In this way, along with the far stronger greenhouse gases methane and nitrous oxide, an estimated 60 to 80 gigatons of carbon pour into the air annually in the form of carbon dioxide. At

left | For sampling, technician Marco Pöhlmann drives an extraction probe into the forest soil. Markus Reichstein, Susan Trumbore, Marion Schrumpf, and Enrico Weber (from left) await the core with interest.

above left | The core cutter provides a soil sample comprising several layers. Later, at the institute, the scientists will examine the composition of the soil from different depths.

above right | Life below ground: Each sample contains innumerable organisms that consume plant material, including earthworms. The latter's excrement, known as earthworm casts, is an important fertilizer.

the same time, humans propel 8 gigatons of carbon in the form of carbon dioxide into the air through the combustion of fossil fuels. "These figures alone demonstrate how significant soil might be for the carbon cycle and thus for the climate system," says Reichstein.

CLIMATE WARMING ALSO HEATS UP THE SOIL

Plants re-absorb the greenhouse gas carbon dioxide through photosynthesis. If the volume absorbed corresponds to that released by soil respiration, the system is in equilibrium and the carbon dioxide concentration in the atmosphere does not change. Some forest areas absorb more of the gas than they release. In total, the soil now contains over 3,000 gigatons of carbon: more than four times as much as the atmosphere.

In the future, however, the soil could release more of the climate-damaging gas than it absorbs, because global warming is also heating up the soil, and the metabolism of the organisms in it is increasing. As a result, the microorganisms will decompose more plant material in less time and exhale more carbon dioxide which, in turn, will further heat up the atmosphere. This could intensify the greenhouse gas effect.

Whether this will happen or whether the system will buffer itself is a matter of some dispute, and as regards concrete figures, the forecasts are imprecise at best. "Most models say that ecosystems will initially continue to absorb carbon," explains Reichstein. "Other prognoses, however, state that the system could swing in the opposite direction due to feedbacks." The soil would indeed then change from being a net carbon sink to a net carbon source.

An international team of scientists working with the French environmental researcher Pierre Friedlingstein carried out test calculations on 11 different carbon-cycle climate models and compared the results. The greatest cause for optimism is currently reflected in the forecast by the Lawrence Livermore National Laboratory in California, which states that the soil will continue to bind carbon dioxide, perhaps even more than it does at present. Another model from the University of Maryland suggests that the soil will behave the same way in the future as it does today.

The bleakest prognosis comes from the results of a model developed by the Hadley Centre in Great Britain. According to this forecast, the soil could release more than three gigatons of carbon annually by the year 2100. "That is probably very overstated, but it is entirely possible that the soil could become a climate heater," notes Max Planck researcher Reichstein.

Which scenario will actually take place depends on a tiny factor in a rule of thumb known as the Van 't Hoff rule. The Van 't Hoff rule describes the inter-

Photos: Sven Döring

action between the reaction rate of the soil as a function of temperature and, therefore, the climate effect triggered by the soil organisms. According to this rule of thumb, soil activity doubles when the temperature rises by 10 degrees. This rule, which is simple textbook knowledge, appeared to describe what happens in reality relatively well.

This was also the case in the context of science, at least thus far. "We now know that this factor dictates how things develop," says Reichstein. "So it is essential that we establish exactly how high this factor is and whether it can change." Will the soil activity double, or will it perhaps increase by a factor of just 1.5? Or will it perhaps even triple? This figure will determine whether the soil remains a carbon sink, becomes a more neutral climate factor, or heightens the greenhouse effect.

The uncertainty surrounding the precise level of the factor in the Van 't Hoff rule is rooted in, among other things, a certain detail relating to biomass decomposition in the soil. The principle is undisputed: microbes metabolize dead material, they breathe out carbon dioxide, and the soil outgases. Other plants die, the microbes attack the fresh biomass and, at the same time, further break down older, pre-digested humus material. What soil scientists do not agree on is how quickly and to what extent the soil organisms break down the fresh biomass and the older material.

FRESH BIOMASS WHETS THE APPETITE FOR OLD FARE

Classic models describe what happens when the temperature increases as follows: Due to the effect of warming, the soil inhabitants eat up fresh biomass faster, but their appetite for the old material remains the same. As a result, soil respiration would increase, but the soil would ultimately remain a carbon sink. "This is precisely what we question. Soil microbes very much lead an independent existence. How they behave may not be quite as easy to predict as was thought," says Markus Reichstein.

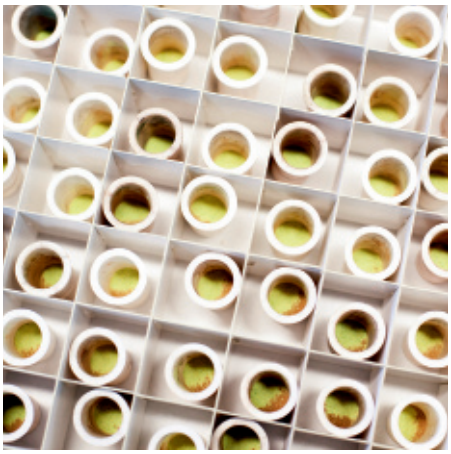
The researcher and his colleagues assume that the priming effect kicks in: "Whenever fresh new biomass is available to the microbes, their appetite for the old humus material increases." The decomposition process accelerates and the soil emits more carbon dioxide. In addition, the microbes thrive and proliferate. "The warmer the soil becomes, the further the system is intensified," explains Reichstein. Fresh biomass acts almost as an aperitif that stimulates the microorganisms' appetite for older food.

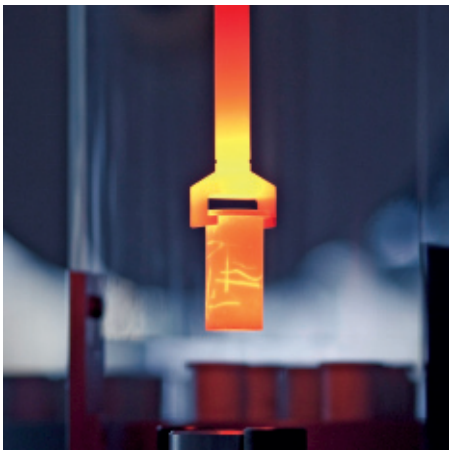
However, some soil processes counteract the decomposition: chemical interactions between minerals hold the carbon in the soil at a constant level. Iron and aluminum hydroxides, for example, often accumulate carbon on their surfaces, from which it initially does not detach.

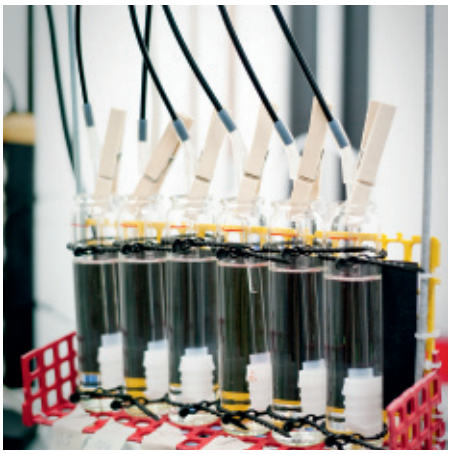
The researchers devised a number of possible mathematical formulas that can be programmed in a computer to calculate as simply as possible and with sufficient accuracy how these processes interact. They want to use laboratory and field experiments to determine which of these formulas is most suitable, so they must now shift their focus below ground.

Reichstein and his colleagues succeeded in attracting millions in funding for their project from the European

Photo: Sven Döring







above | To enable the measurement of their carbon and nitrogen content, the soil samples are ground and weighed in ceramic crucibles (left). The yellow color comes from tungsten oxide, which acts as a catalyst. An automatic sample dispenser assists in determining the total carbon content (center). The crucibles with the samples are heated to a temperature of 1,100 degrees Celsius for this purpose. The researchers examine the conversion processes in the soil in automated incubation experiments under controlled temperature and humidity conditions (right).

left | The work begins in earnest back in the laboratory: Markus Reichstein presents dozens of soil samples that are dried before being analyzed – here in a greenhouse due to lack of space.

Research Council (ERC). As part of the QUASOM project (quantifying and modeling pathways of soil organic matter as affected by abiotic factors, microbial dynamics and transport processes), they aim to merge data from new field experiments with data from other European research projects in a soil simulation model.

Marion Schrumpf from the biogeochemical processes department brought valuable experience with field data to the team, having already collected field data as part of the Carbo-Europe project (Assessment of the European Terrestrial Carbon Balance). This project explored the question of how the activity in the soil changes over time throughout the continent, and how forests and arable areas can be managed so that their soils bind as much carbon dioxide as possible. Sixty-one research institutes from 17 European countries participated in this project, which was headed by the now retired Founding Director of the Max Planck Institute in Jena, Ernst-Detlef Schulze.

The researchers involved frequently broke new methodological ground. "A comprehensive soil inventory had simply never been carried out before," reports Marion Schrumpf. The data available on forest soils, for example, is extremely sparse. "The forestry sector was interested in its tree population, but not in the soil on which they grow," says the researcher. The little data available stems from agriculture. Farmers and agricultural scientists have been observing how arable soils react to different management practices for more than 100 years. These long time series of soil analyses can now be used to learn something about the effect of climate change on soil carbon. However, the agricultural data is often far from complete. "Besides, this work was carried out from an entirely different perspective," says Schrumpf. Agriculture is interested primarily in information about soil fertility. The scientists working on Carbo-Europe and QUASOM, on the other hand, look at the soil from the perspective of climate research: high carbon content in the soil not only increases fertility and yields, but also means that carbon is being removed from the air.

As part of Carbo-Europe, Marion Schrumpf worked on core samples from 12 locations. The samples were taken in places that also had towers for atmospheric measurements. "As a result, we had a good supply not only of soil data, but of other environmental parameters as well," says the researcher. She examined a total of more than 9,000 samples – an enormous undertaking.

IT IS NOT ENOUGH TO SIMPLY GO OUT AND DIG

It starts with sampling: "Life would be easy for us if the world were just a pile of sand," says Schrumpf. "It isn't enough to simply go out, dig a bit, and bring back a mound of soil, as people might think." That is why she drives a core sampler into the subsoil. "That can be very strenuous," says the researcher, as many soils are rock hard. And the deeper they penetrate, the more solid they become.

"Besides, you can't simply put some soil into plastic bags to get samples," says Schrumpf. "For quantitative tests, you have to remove a precisely defined volume of soil from the earth and know the depth from which the sample originates." And because the scientists in this project are interested

Photos: Sven Döring

Data analysis on the computer: Markus Reichstein analyzes the CO_2 flows from the soil into the incubation containers. The window provides a view into the climate chamber where Stefany Thiessen, a doctoral student working on the QUASOM project, monitors one of the 80 containers.

in how soil changes over time, they will have to sample the same places again in a few years.

UNDERWORLD PROCESSES IN THE LABORATORY

The sampling for the Carbo-Europe project has since been completed, but the analytical work continues in the laboratory. Schrumpf sorts the roots from the samples, dries them, sieves and grinds them, and then measures their carbon content: "It takes at least 45 minutes per sample, not including the drying time." It is planned to examine some of the locations regularly in the future – ideally over a period of decades. Schrumpf and her colleagues will then repeat the entire procedure again.

The soil researchers will also be heading out regularly to collect samples for the QUASOM tests. As was the case with Carbo-Europe, the researchers will put the soil samples to work under controlled conditions in the lab. "We can control each factor individually – from the volume of fresh material added, to the temperature, humidity and wind conditions – and examine how a particular soil reacts under certain conditions," says the head of the research group, Markus Reichstein. In this way, the scientists can track the individual processes that occur below ground and find out what happens and how under very specific conditions.

But laboratory experiments also have their limitations: they provide data about an artificial subsystem; the real conditions outside could be very different. The researchers thus also want to carry out additional tests in the field. The data obtained there may be less accurate, as it is more transitory due to the effect of wind and weather, but taken together, the field and laboratory values provide a solid knowledge base.

This is supplemented by values from the air, obtained as part of the Fluxnet project, a global network of carbon dioxide and water vapor measurements. Along with the vertical wind speed, the carbon dioxide and water concentrations in the air layer above ecosystems are determined 10 to 20 times per second. Reichstein and his team use these values to deduce the amount of the two substances exchanged between the soil system and the air. The great advantage of this type of measurement is that it does not influence or alter the ecosystem itself. The measurements can thus continue for many years without concern. Satellite data help transfer the information to larger areas, even entire continents.

All of the data collected by the project ends up in the computers of Thomas Wutzler and Christian Beer,

Photo: Sven Döring

the team's computer scientists. Wutzler analyzes the data statistically and feeds it into the previously formulated models. All of the models are theoretically coherent and consistent and therefore equally plausible. The formula that best conveys the reality as gleaned from the new data will eventually be incorporated into the global climate simulation. This is Beer's responsibility. His large-scale simulations combine the local, regional, national and continental studies to produce a comprehensive picture.

Reichstein's team is now also enjoying additional prominent scientific support in its attempt to clarify the role of soil in the global greenhouse: Susan Trumbore, Ernst-Detlef Schulze's successor, joined the Max Planck Institute for Biogeochemistry in September. As part of her previous research in America and Switzerland, Trumbore focused on, among other things, the question of how the potential of soils as future sources of carbon dioxide can be calculated. "We want to work closely together on this," Trumbore and Reichstein agree.

And much remains to be done. It is still far too early to obtain reliable soil forecasts – if possible for the whole world, and for centuries. It will be years before this stage is reached. "The soil holds some of the last secrets of the Earth system. We need to uncover these to be able to provide better and more reliable climate forecasts," says Reichstein. ◂

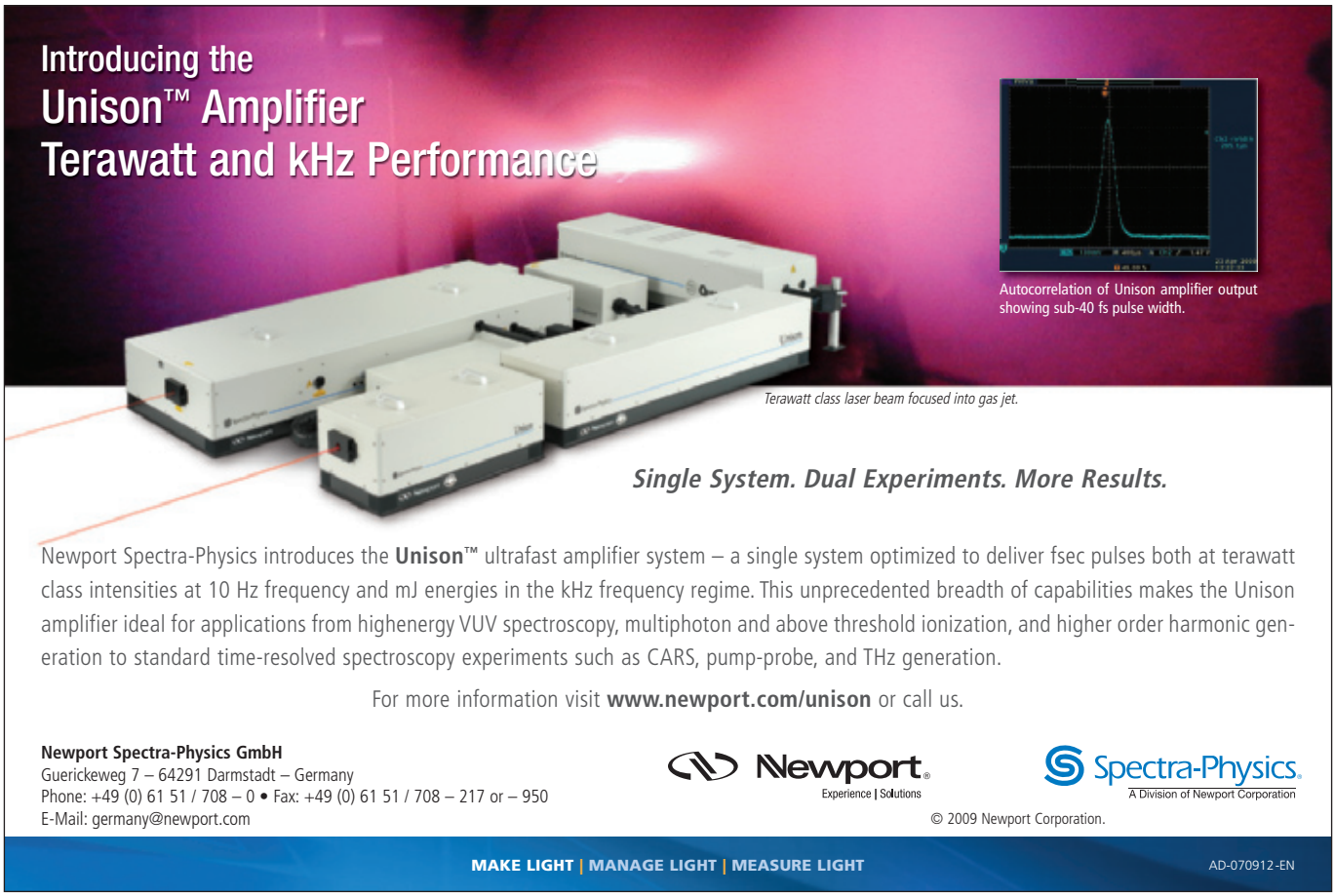
GLOSSARY

Priming effect
Certain substances, such as fresh biomass, can increase the general activity of microorganisms in the soil.

Carbo-Europe
A project aimed at understanding and quantifying Europe's terrestrial carbon balance.

Fluxnet
A global network of micrometeorological towers that measure the exchange of carbon dioxide, water vapor and energy between ecosystems and the atmosphere.

QUASOM
A project aimed at attaining a better understanding of the interaction between biological and physical-chemical processes in the soil.



Do Bonuses **Do the Trick?**

Management bonuses that provide the wrong incentives are regarded as one of the causes of the recent financial crisis. At the **Max Planck Institute for Research on Collective Goods** in Bonn, **Carsten Burhop** is studying how bonuses affect corporate success – except he has chosen historical examples to work on. After all, rewards designed to motivate managers, as well as inventors, were used as far back as the late 19th century.

TEXT **BIRGIT FENZEL**

Not very long ago, a daily paper in southern Germany ran a lead in its business section entitled "Bonus greed sparks first legal probe." The gist of it was that bank managers could find themselves in court to explain their dubious bonus practices. Apparently two stockbrokers at Westdeutsche Landesbank (WestLB) were likely to face charges for covering up high-risk transactions in order to not jeopardize their bonuses. This would be the first case of its kind to come to court in Germany.

This news marked the culmination to date of the debate surrounding the compensation system for top business managers in general and bankers in particular. Was this another case of men in high places sweetening their annual salaries with juicy extra payments despite recession and economic crisis? There has been widespread anger worldwide that the very people who are now blamed for causing the global economy to falter are lining their own pockets.

ACCIDENTAL DISCOVERY AROUSES CURIOSITY

Sitting in his office at the Max Planck Institute for Research on Collective Goods in Bonn, Carsten Burhop glances through the paper. The 36-year-old economist has an eye for the reports on management salaries and bonuses that are currently resurfacing on the business pages. His interest in the subject, however, predates the financial crisis by a long way. "While I was working on my doctorate in the archives, I accidentally came across some bank directors' employment contracts. That would have been in 2001, when the same subject was also being talked about – you remember the Enron case. Since then, I have taken things a little further," he explains.

In practice, "a little further" means that Burhop and his colleague Thorsten Lübbers have been delving into the archives of libraries, banks and major companies all over Germany. He has lost count of the hours he has spent poring over dusty piles of old stock market reports, balance sheets, patent specifications and salary agreements. But he clearly remembers stumbling across the odd fact here and there that is likely to be highly relevant to the current debate on the sense and nonsense of the bonus culture. The purpose of his project is to establish whether bonuses and performance payments genuinely lend themselves to heightening the discipline and motivation of managers.

As an economist, Burhop is particularly interested in how the additional pecuniary compensation impacts a phenomenon known to economics as the principal-agent problem. In simple terms, this refers to a serious conflict of

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interest, for example between employer and employee, or between shareholder and corporate executive. In the case of non-standardized activities, such as managing a corporation in the interests of the shareholders, the principal is unable to perceive the actions performed by the agent or, as in our example, the shareholder is unable to perceive the work of the executive and its impact on profits and share prices. Besides, it would be far too costly for the principal to meticulously track the activities of the agent. The interests of both parties must thus be made to converge. One possibility for this lies in the structure of the employment contract.

THE DANGLING CARROT

"If shareholders want to see a rising share price, they should make the salaries of senior executives dependent on the share price moving in the right direction," says Burhop. On the other hand, there is also the consideration that the attraction of money lessens when you already have a lot of it. In other words, the more a manager earns, the more he or she must be incentivized. There is also the question of whether such behavior patterns can be controlled through external incentives. But if a donkey performs better with a carrot dangled in front its nose, why should the principle not be transferable?

In fact, there is nothing new about using rewards to enhance motivation. It happened in ancient Rome, says Burhop. "In his correspondence with Trajan, Pliny the Younger wrote that workmen can be induced to work harder if they are rewarded for it." It was not until the end of the 19th century, however, that bonuses as we know them became widespread in German commerce, as Burhop has discovered in his archive research.

It was no coincidence that his project focuses on the late 19th and early 20th centuries. That was a period of dramatic technological and institutional change and rapid economic growth, and thus promised a wealth of insightful material. This was a time at which faster communication by rail and telegraph made it possible to administer larger business undertakings, many of which took the form of stock corporations. These new big businesses also fostered the creation of new internal functions, for example in the field of research and development. Indeed, the whole success story of 19th century industrial expansion and the years that followed was essentially the result of the new technological developments that emerged from corporate research departments.

A PATENT SOLUTION TO CONFLICT

The patent offices, however, regularly credited the inventions made by salaried researchers to the companies rather than to the actual inventors. Therefore, in this domain, too, employers found it necessary to resolve the conflict between their desire for the maximum of profitable innovations and the interests of their research department employees. As Burhop describes the principal-agent problem of the time, "Why should someone invest work and effort in an invention from which he or she derives no direct benefit?"

Bayer, BASF, Hoechst, Siemens and Merck – the powerhouses of German industry in the days of the German Empire – all allowed the two econo-

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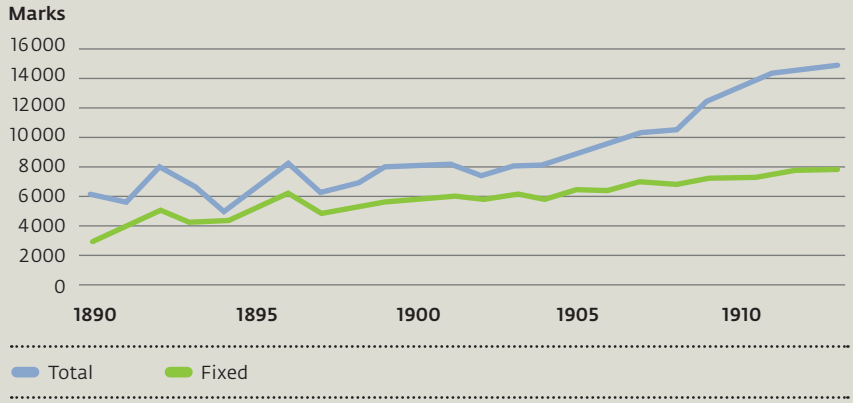
mists from Bonn to view their personnel department archives. Burhop and Lübbers found the employment contracts with research department staff at BASF, Siemens and Bayer particularly revealing. As they were able to reconstruct from the pay records, until the 1890s, there was little or no difference between the employees' fixed salaries and the amounts they actually received. "Of all the companies we studied, Bayer was initially the only one to address the principal-agent problem with the introduction of contractually agreed bonuses. Under specified conditions, the extra money paid was calculated on the basis of the profit that each innovation brought in," says Burhop. Prior to 1890, the bonuses paid by Bayer averaged no more than 1 percent of salary. It was not until after the turn of the century that the proportion of variable compensation paid to research and development staff increased to 17 percent of total income. By contrast, BASF and Siemens had no explicit bonus systems, but paid rewards for creative achievements that promised to yield a profit.

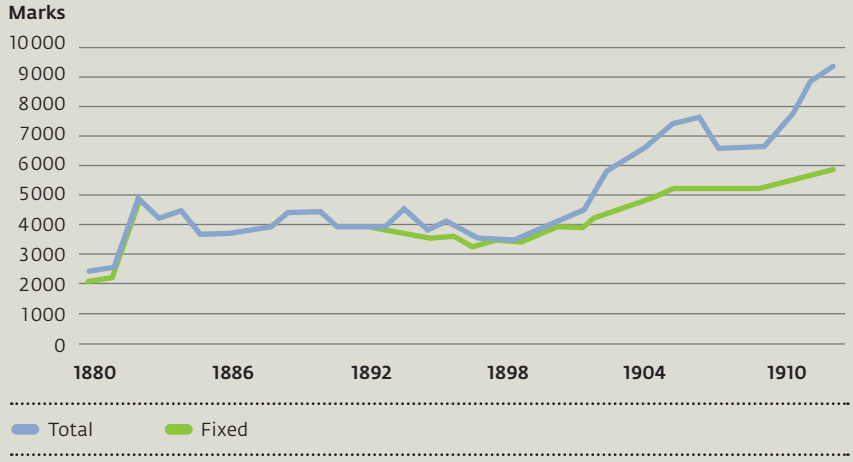
In their analyses of differing incomes and the number of patents the

Chart: designergold, based on material from the MPI for Research on Collective Goods

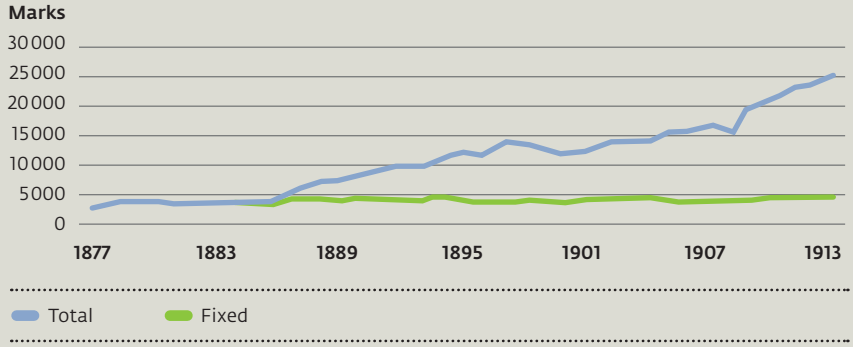
AVERAGE INCOME OF RESEARCH SCIENTISTS AND TECHNICAL STAFF AT SIEMENS, 1890 TO 1913



AVERAGE INCOME OF CHEMISTS AT BAYER, 1880 TO 1913

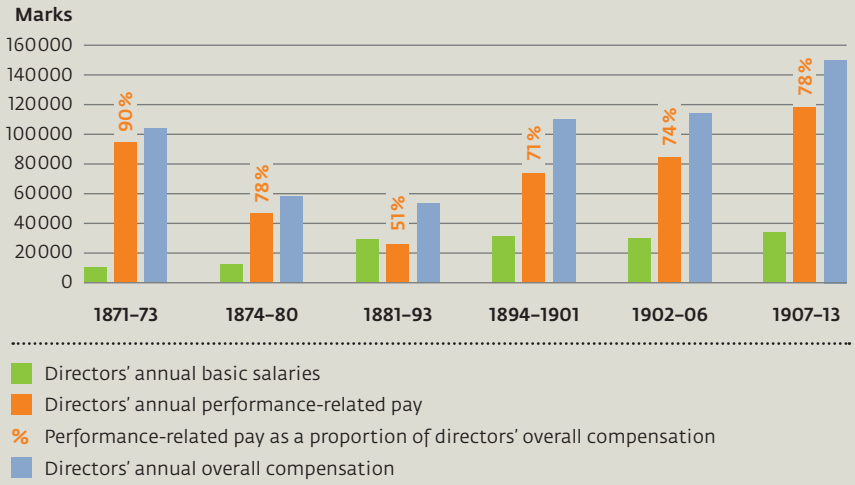


AVERAGE INCOME OF CHEMISTS AT BASF, 1877 TO 1913

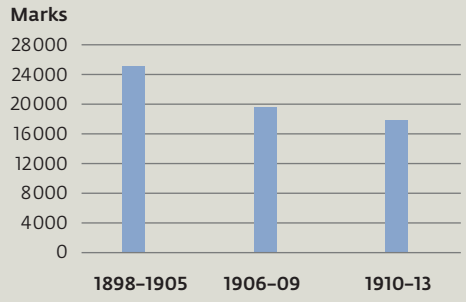


Until the 1890s, there was little difference between fixed salaries and actual payments. Not until after the turn of the century did the proportion of bonuses paid to research and development departments rise substantially.

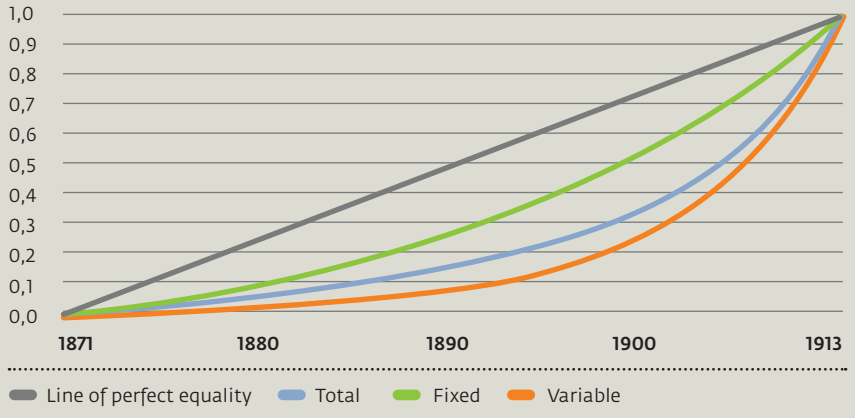
DIRECTORS' COMPENSATION / SALARIES



GUARANTEED OVERALL INCOME PAID TO DEPUTY DIRECTORS



LORENZ CURVE ILLUSTRATING BANK DIRECTORS' INCOME, 1871 TO 1913



The Lorenz curve (above) measures the concentration of income on a small number of persons. The further the curve from the line of perfect equality, the more strongly income is concentrated on fewer persons. Variable compensation was thus more strictly limited to a few managers than fixed compensation. The incentives were concentrated on a small number of them.

companies registered each year, the economists came across an interesting correlation: "It is not just the amount of pay that motivates an employee, but the way that pay is structured," explains Carsten Burhop. The effects can be inversely proportional: That is to say, when salary is increased by 1 percent, the number of high-quality patents declines by 0.6 percent. As the economists from Bonn discovered, increasing compensation in this way does anything but improve performance. But upping compensation in another way certainly does increase motivation: when the proportion of income paid as bonuses grows by a factor of 1.1, the number of patents rises by around 2 percent.

To illustrate the arithmetic, Burhop quotes the example of a researcher earning 50,000 euros in the form of a base salary of 40,000 euros and a 10,000-euro bonus: "To date, he or she has been filing 1,000 patents each year. Increasing overall income by 1 percent, from 50,000 to 50,500 euros, would have the effect of reducing output to 994 patents – if he or she simply received a higher base salary." But the picture is very different if the extra in-

Chart: designergold, based on material from the MPI for Research on Collective Goods

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come is paid as a bonus. "In this variant, the bonus element of the overall income rises from 20 to 20.8 percent, so by a factor of 1.04." The number of patents thus increases by 8.

BRINGING A SMILE TO THE COAL BARONS' FACES

"This bonus effect of 8 additional patents more than cancels out the "6 patents fewer" effect of the higher total income. So overall, the number of patents increases from 1,000 to 1,002." Viewed in this way, there is an identifiable effect of bonuses on patentable inventions, but it is "very small and is visible only after a few years."

The two economists came up with similar results when they studied the data on coal mines in the Ruhr region in the 20th century and the effect of bonus payments to the managing directors. Such bonuses had been a common feature at stock corporations since the mid 19th century. Apart from bonuses, the pit owners in the early industrial years had little opportunity to influence the work of the directors in their masters' favor.

Burhop and Lübbers took a special interest in mines organized in a syndicate. Economists hold such groups in low repute. "Cartels encourage laziness," says Carsten Burhop, summing up a theory formulated by Nobel laureate Sir John Richard Hicks following his studies of syndicates in general: the biggest profit a monopoly earns is the quiet life its managers enjoy.

Our researchers set about testing this theory against the example of 28 mining companies in the Ruhr region. "The cartel that some of these firms formed minimized the competitive pressure and ensured that prices and production remained stable," says Burhop, citing the economic benefits the coal barons reaped from this policy.

To test the laziness theory, the two researchers used a mathematical model to estimate how high production could be under ideal conditions – firstly for pits exposed to the full impact of market forces, secondly for mines in a syndicate, and thirdly for companies that paid bonuses. They evaluated the number of miners and the value of the machinery and equipment used as input factors and related these to the annual output of coal.

The result surprised them both. Apparently Hicks' assessment doesn't necessarily apply to every syndicate. "It was clear that the efficiency of the mining companies was not significantly affected by membership in a cartel," Burhop explains. But he found another observation even more interesting: "Efficiency was far higher at those firms that paid substantial bonuses to their directors." On average, the pits paid their boards of directors some 77,300 German marks in bonuses. "Just by comparison, a miner earned 1,000 German marks a year in those days," adds Burhop.

Here too, Burhop and Lübbers established that 1 percent more in bonuses was enough to change the picture. For example, friction losses in production were reduced by 0.0035 percent – simply through better management and making more economical use of the means of production. With an average company losing 22.66 million marks due to efficiency losses in those days, that equates to savings of 790 marks. To achieve that, however, the shareholders had to pay an additional 773 marks in bonuses to their directors, leaving them just 17 marks bet-

ter off. Consequently, the owners of the mines gained little benefit from addressing their principal-agent problem with the directors they employed via the bonus route. "Of course the national economy benefits when efficiency is boosted," says Burhop: "But that was not the purpose the mine owners had in mind in paying bonuses."

The example of the coal mines in the Ruhr region shows that bonuses can work. On the other hand, their effect is minor and highly dependent on the intended goal. "The problem is not so much the idea itself, as that it channels the work effort in one direction," says Burhop. That is why he is not in favor of a general ban on bonuses, which would be more likely to harm the economy. But specifying the wrong goal can have an adverse effect. In Burhop's opinion, the present financial crisis is an example of the fatal consequences of single-minded fixation. "If I get a bonus that is directly dependent on this year's profit, I am not going to bother about next year," he continues. It was this kind of motivation that caused bankers to gamble away huge assets in pursuit of short-term gains.

When bonuses are linked to goals of this nature, they constitute a genuine source of risk. That is why, after steeping himself in historical research, our economist believes that stronger controls of the kind demanded by politicians and economic commentators are entirely appropriate. It is quite possible that the interests of business owners might even be more effectively asserted through transparency and control rather than through bonuses and other incentives – at least that was the case in the past, as research conducted by Carsten Burhop and Christian Bayer shows. The economic boom in the early years of German industrialization was followed in 1873 by a major crisis. After lengthy debate, the government responded in 1884 by reforming corporate law with stricter rules, tighter controls and harsher penalties. Prior to that time, only major shareholders had access to general meetings and made decisions on company affairs. There were few controls over the success or failure of directors, and getting rid of incapable bosses was a tortuous and expensive process.

After the law was reformed, all shareholders were permitted to attend general meetings where they had the right to vote and receive information on the company's performance in the form of a profit and loss account. The new rules also made it easier to dismiss directors who, as a result, found themselves having to make the effort without the extra pay. The monetary incentives for directors were nearly halved. Later on, more extensive regulations were introduced – such as a special tax on profit-share payments – but there is no doubt that the rules adopted in 1884 were a success. Our Bonn-based economist sees his task to be one of basic research rather than recommending solutions to current problems. But he has no objection to contributing his findings to the discussion on what action to take to keep business leaders on the straight and narrow. "After all, what worked in the days of the Empire might well also work today." ◂

Dietmar Grosse

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ALLES WAS DIE WISSENSCHAFT BEWEGT

Sweating in the Service of Science

A washboard stomach takes discipline – and a good exercise program. **Erich Albert Müller** from the **Max Planck Institute for Occupational Physiology** studied the best way to develop muscle. Today, more than 50 years later, the basic principles Müller described remain valid – as do many of the insights from the research carried out in the field of occupational physiology at the time.

TEXT **ELKE MAIER**

At the Kaiser Wilhelm Institute for Occupational Physiology, riding a bicycle following the consumption of half a bottle of liquor and two liters of beer – something that would attract hefty penalties in the road traffic context – was a remunerated activity. The scientists at the institute wanted to find out how alcohol affects the performance of manual laborers. To this end, they appointed a test subject and put him to work on the ergometer: in a long-term experiment lasting six months, the test subjects "consumed half a liter of Münsterländer corn schnapps and four (0.5 l) bottles of Dortmunder beer on the alcohol days."

According to the experiment protocol, sometimes the test subject was also allowed to get drunk on the day of the experiment itself, and occasionally even the night before. The scientists comment on the decline in the work performance of the test subject as follows: "Our experiments show that the hangover effect triggers a quantitatively stronger and more dramatic deflection of the performance curve than the direct consumption of alcohol." Indeed, if alcohol was instead consumed shortly before the start of work, the same volume of alcohol had a positive effect on performance. Conclusion: "The less work is perceived 'as a burden', the more intensive and untainted is the test subject's willingness to work." The aim of the experiments was not, however, to recommend alcohol as a means of increasing performance, but to describe the effects of alcohol consumption, which, in the past at least, was very common among not only manual workers.

Far from devoting their efforts exclusively to exploring the effects of intoxicants on performance, the scientists at the Kaiser Wilhelm Institute for Occupational Physiology, founded in 1912, were dedicated to the "scientific research of the physiology, pathology and hygiene of mental and physical work" and thus aimed to illuminate as many aspects of the field of occupational physiology as possible.

Body building with visible results: Erich Albert Müller with one of his test subjects at the Kaiser Wilhelm Institute for Occupational Physiology.

Photo: KWI for Occupational Physiology

In 1929, the institute moved from Berlin to Dortmund in the Ruhr area, the very center of hard physical work in Germany. There, in the mine shafts and the scorching furnaces of the steel works between the rivers Rhine and Ruhr, the physiologists found the precise conditions in which they were so interested and that enabled them to explore a wide range of research questions. For example: How does physical work influence health? What nutrients does the body need in order to withstand enormous physical strain? The scientists at the institute developed a series of unusual experiments to find answers to questions of this nature.

THE ULTIMATE BODY-BUILDING FORMULA

They researched the dust-filtering characteristics of the human nose, for instance. To this end, they blew dust into the noses of test subjects. As a result of this work, they discovered a correlation between dust-binding in the nose and silicosis (black lung): "It turns out that silicotic changes are more likely to occur in miners whose noses do not filter dust well, and that such changes are more severe in these miners than in miners whose noses have good dust-binding capacities (…)."

In another experiment, the researchers placed a test subject in a climate chamber and had him ride a bicycle in the service of science, in this case for several hours at temperatures of up to 46 degrees Celsius, with and without access to liquids. The subject's sweat was meticulously collected to measure the volume of chlorine it contained. The young man was weighed before and after the experiment to enable the researchers to extrapolate the volume of sweat produced. The aim of this experiment was to discover how heavy physical work at high temperatures affects the body's mineral metabolism and performance capacity.

In contrast, the experiments that Erich Albert Müller introduced as department head at the institute in Dortmund centered on muscular activity of a decidedly less sweaty nature. Together with his colleague Theodor Hettinger, Müller discovered the ultimate bodybuilding formula in the 1950s, by which time the Kaiser Wilhelm Institute had been renamed the Max Planck Institute for Occupational Physiology. The two scientists studied the cor-

relations between training stimulus and muscle strength in untrained test subjects of both sexes: "We observed that contractions involving less than about one third of maximum strength do not train the muscle. If the contraction of a muscle exceeds one third of its maximum strength, its mass grows and hence also its strength," wrote Müller.

What was surprising about this was the discovery that strength increases at a maximum rate if the muscle is contracted at only half of its maximum strength. Moreover, it was discovered that contraction of only a second's duration per day was sufficient to achieve the maximum possible increase in strength. Although these values have since been corrected – it is assumed today that, ideally, muscle should be contracted around five times per day for five seconds and each time at 70 percent of maximum strength – the basic principles still apply: to attain maximum effect for minimum effort during strength training, the intensity, duration and frequency of the load should be correctly metered.

But the researchers' interest was not restricted to just industrial work. One research group at the institute focused on energy consumption during the most common of all activities: housework. For this study, the scientists fitted three Dortmund housewives with facemasks and respiratory gas meters and monitored them in the course of their everyday activities. Everything was meticulously recorded, from the darning of socks and buttering of bread to the mangling of laundry and polishing of floors. Based on the women's oxygen consumption, they calculated their energy expenditure and made recommendations as to how the housework could be streamlined – for example through the "general introduction of time- and calorie-saving household appliances."

Dortmunder Zeitung of October 22, 1929

» Many specialized departments with first-class expert researchers from the most wide-ranging disciplines [at the Kaiser Wilhelm Institute for Occupational Physiology] all pursue the same aim: to improve the working lot of human beings by organizing the work process in an optimum way for both humans and their work.

Along with the household, agriculture provided another research focus for the institute. In this context, the researchers explored the question of how walking on different kinds of arable soil affects the energy needs of farm workers. The quest for the most favorable form of basket – from an occupational physiology perspective – for potato planting presented another fascinating challenge for the scientists. The findings: a worker burns 70 percent more calories while walking in a stubbly field or in a potato furrow than when walking on smooth soil. Furthermore, kidney-shaped baskets with shoulder straps are more suitable than oval baskets with handles because they align better with the surface of the body and reduce the static work required.

Role reversal: Erich Albert Müller, this time as a test subject himself in an experiment on the "Energetics of the vertical downward-directed pull movement." The photograph is from Müller's postdoctoral thesis of 1930.

Erich Albert Müller retired in 1966 and settled in Freiburg, where he continued to work with undiminished enthusiasm. In his self-built laboratory, he tinkered with improvements to ergometers and continued his research on muscle training. When he died in 1977, he left behind a body of work comprising more than 300 scientific publications, some of which are regarded as seminal contributions to the science of ergonomics.

Müller's reputation was established in particular by his definition of a performance pulse index (*Leistungspulsindex*), which specifies the individual limit of physical endurance. This pulse endurance limit inspired renowned sports medicine specialist Wildor Hollmann to develop a similar principle, the anaerobic threshold, in 1959 and, based on this, lactate measurement, which is now an indispensable tool in both competitive and recreational sports.

Müller did not limit the use of his technical skill to the further development of useful devices such as ergometers, pulse-measuring devices and respiratory gas meters. While still living in Dortmund, he provided an unforgettable reception to his visitors with the help of an original and ingenious technological device: when anyone rang his doorbell, the door opened as if by magic, and a moving step conveyed the astonished guest through the door.

Nevertheless, Müller was, in principle, an ardent supporter of stair-climbing as an activity: "To maintain the body as an energy machine at a standard level of performance, all you need are your own four walls (...). However, to keep the heart and circulation working well, it is also necessary to run up a staircase at top speed for ten seconds every two to three days." ◂

Photo: KWI for Occupational Physiology

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Max Planck Scientists Keep It Simple

Stefanie Höhl (MPI for Human Cognitive and Brain Sciences), Christian Vollmer (MPI for Chemistry) and Theobald Lohmüller (MPI for Metals Research) are three of a total of six winners of the Klaus Tschira Prize for Understandable Science.

Stardust need not be as dry as dust, but can actually be quite exciting, as Christian Vollmer of the MPI for Chemistry vividly demonstrated. He is one of a total of six winners of the Klaus Tschira Prize for Understandable Science presented this fall. The award is given to doctoral students who write a report that enables the general public to appreciate the subject of their doctorate. The theme of the award is: "Keep It Simple! – so that others can understand what you have discovered." No fewer than three scientists working at Max Planck Institutes took on the challenge with particular success: geologist Christian Vollmer, psychologist Stefanie Höhl and chemist Theobald Lohmüller. Stephanie Höhl investigated the reactions of small children to their parents' facial expressions at the MPI for Human Cognitive and Brain Sciences, while Theobald Lohmüller, under the aegis of Joachim Spatz at the MPI for Metals Research, looked into just what moths' eyes have to do with nanotechnology. The award is presented by the Klaus Tschira Foundation, whose patron is Max Planck President Peter Gruss. The founder, Klaus Tschira, wants to encourage greater appreciation of aspects of the natural sciences, and is himself a Senator of the Max Planck Society. The prize-winning papers were reprinted in a special insert in the German-language magazine *bild der wissenschaft*. The winners each received 5,000 euros in prize money.

Six Max Planck Researchers Receive EU Starting Grants

The European Research Council (ERC) announced in September the scientists and projects that would benefit from the second round of ERC Starting Grants: a total of 240 scientists from 19 countries (including Israel) will share some 325 million euros in sponsorship funds. Each of them will receive up to 2 million euros over a five-year period. The ERC received a total of 2,500 applications. Among the winners are 27 scientists from Germany, including 6 Max Planck researchers: linguist Michael Alexander Cysouw from the MPI for Evolutionary Anthropology, Nicholas Enfield from the MPI for Psycholinguistics, Stefan Diez from the MPI for Molecular Cell Biology and Genetics, Gunter Meister of the MPI for Biochemistry, Marc Strous of the MPI for Marine Microbiology and Sylvie Roke of the MPI for Metals Research. According to ERC President Fotis Kafatos, the ERC Starting Grant is intended to make it easier for the best emerging scientists to start out in their careers. Looking ahead to the future, President Kafatos announced that the program would be split into two, with one part for scientists with two to six years of post-doc experience, and one for those with six to ten years' experience.

Photos: Klaus Tschira Stiftung – Bernhard Kreutzer

Advising the Advisers

EU Working Group networks with University Liaison Officers

The EU Working Group of the Max Planck Society and the Federal Working Group of EU Liaison Officers at German Universities (BAK) came together for the first time in late November for a joint conference in Brussels. In addition to several presentations detailing EU programs, the main item on the agenda involved networking with representatives of the EU Commission.

"Our meeting was very fruitful and we intend to continue to work together," said Rüdiger Hesse, head of the Brussels office of the Max Planck Society. "The BAK has structures that we can learn from, not least because it has existed for longer than our MPS Working Group." For example, the BAK has an extensive website. "The meeting also served to develop contacts between our regional offices and the EU Commission," Hesse continued. The MPS Working Group and the BAK intend to organize further shared events in the future. The conference in Brussels was jointly directed by Rüdiger Hesse and BAK spokesman Andreas Hebbelmann.

Hesse was delighted about the interest the event attracted: "We invited 15 members of the EU Commission to attend our meeting, and almost all of them came." The main focus on the first day was on the COST program (European Cooperation in Science and Technology), which mainly promotes scientific exchanges and strategic conferences. Application for the relevant funds is a straightforward procedure. COST director Martin Grabert and several of his colleagues described the individual elements of the program. "To make an initial application, all that is needed is a rough sketch. In fact, the program is also attractive for junior scientists," explained Rüdiger Hesse. More than a hundred MPS scientists have already received support via COST, which is now financing exchange programs with New Zealand, Australia and Canada.

The theme for the first evening of the event was "Personal networking with the European Commission." Guest of honor was Herbert von Bose, Director of the industrial technologies department at the Research Directorate of the EU Commission. Mr. von Bose agreed with the representatives of the MPS and the German universities that basic research should also be given greater priority in the industrial research sponsored by the EU. Rüdiger Hesse summed up the common ground they shared: "In this respect, we at the Max Planck Society are more in agreement with the universities than other non-university institutions involved in the research program."

The participants from the two working groups also agreed to organize further meetings in the future. They already have their eye on a somewhat larger-scale event involving the national contact point for the Federal Ministry of Research, the Brussels office of the scientific organizations coordinating body KoWi, and the Leibniz Association. "We are all motivated by the fact that the framework programs have become so complex over time that we, as advisers, are ourselves in need of advice," Hesse explained. The overall amount of funding made available by the EU for research activities is enormous: the 7th Framework Program that runs from 2007 to 2013 is valued at around 53 billion euros, and an additional 10 to 20 billion euros is available under various other special programs.

Photo: Michael Ehry

Group Heads Issue Networking Invitation

LeadNet is an initiative launched by the heads of groups, teams and projects with the aim of establishing and maintaining future contacts beyond the limits of individual institutes. They are inviting all junior scientists with leadership responsibilities to an initial meeting at Schloss Waldthausen in Mainz (Photo). The conference, to be held on Thursday and Friday, May 6 and 7, 2010, is intended to facilitate the exchange of ideas on scientific and organizational matters. Following an introduction to the organizational structure of the Max Planck Society, the agenda will include such topics as: finding scientific mentors, guiding doctoral students, applying for national grants, and writing press releases.

The meeting will also include a session devoted to "Computational Biology" and a special round of discussions for heads of Independent Junior Research Groups. Those interested in taking part can register for the conference online. Further details are available at www.leadnet-mpg.de. The closing date for registration is February 28, 2010.

PhDnet Meeting in Jena

The smallest possible network in which a doctoral student might find himself/herself generally comprises the student, his/her Ph.D. supervisor and the contacts he/she makes in the course of his/her scientific work. To extend horizons beyond the bounds of this small group, there is PhDnet: the joint body of doctoral students at the various Max Planck Institutes.

Small enough to focus on specific interests, yet large enough to provide interaction between the numerous MPIs and their thousands of employees. For guests attending the event in Jena at the end of October 2009, the annual general meeting was positive proof that the network has a real and a virtual side. A total of 85 representatives from 49 MPIs met in the city that is home to the MPIs for Biogeochemistry, Economics and Chemical Ecology.

The meeting elected the new members of the steering committee, who will officially take up their posts at the start of 2010: Daniel Kalthoff (MPI for Neurological Research) will replace Leonard Burtscher as spokesperson; Section representatives Sandra Schöttner, Susannah Burrows and Axinja Hachfeld will be succeeded by Stefan Klatt (MPI for Molecular Genetics), Veronika Bierbaum (MPI for Colloids and Interfaces) and Alexander Jehlin (MPI for Intellectual Property).

From left to right: Susannah Burrows, Veronika Bierbaum, Stephan Klatt, Daniel Kalthoff, Alexander Jehlin, Leonard Burtscher

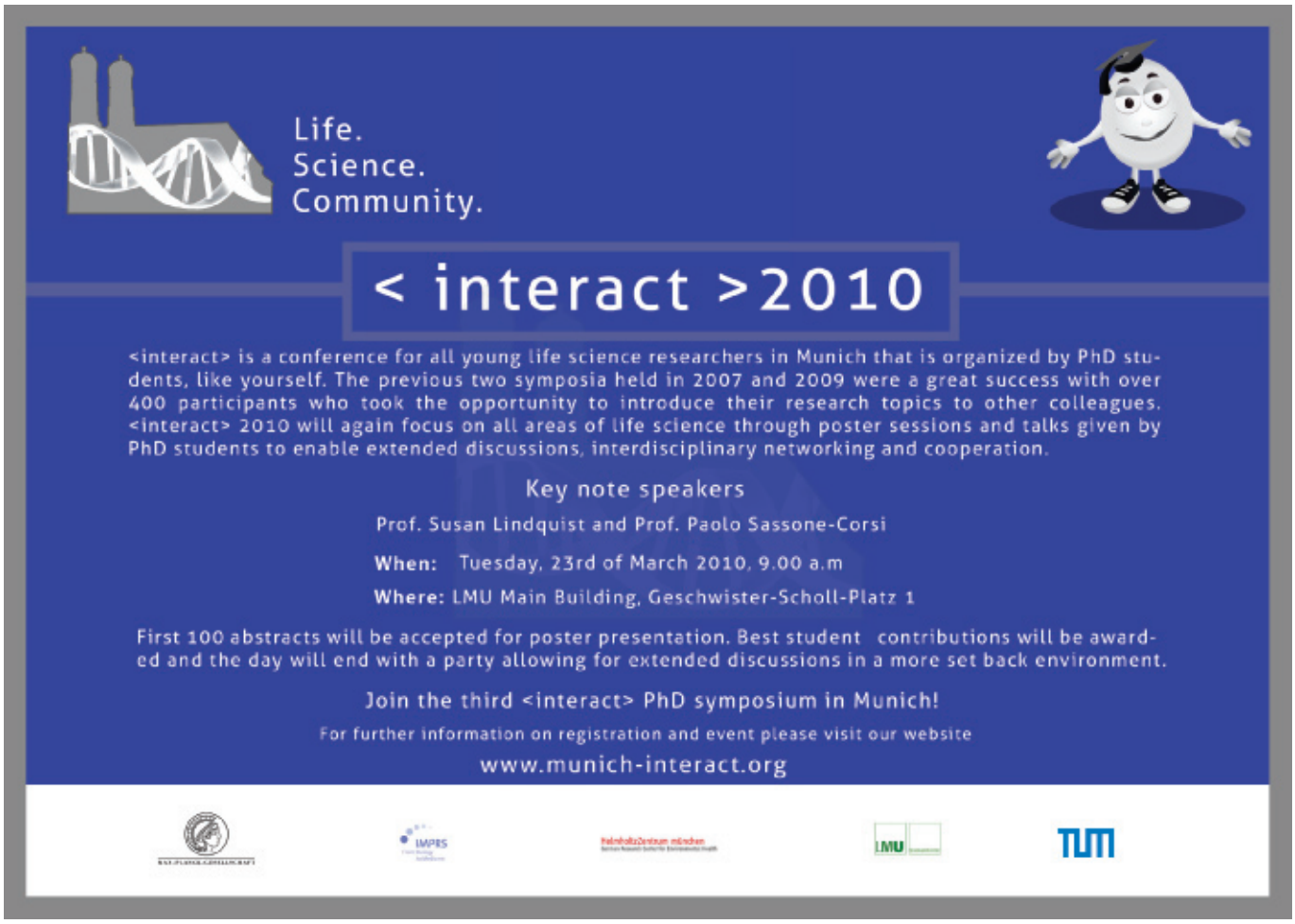

Photo: Max Planck PhDnet

Cooperating in Innovative Fields

Scientists at all stages of their careers are working together on some 50 joint projects

מכון ויצמן למדע
WEIZMANN INSTITUTE OF SCIENCE

The Weizmann Institute of Science is one of the few institutions in the world that shares a mandate similar to that of the Max Planck Society: it promotes state-of-the-art basic research at several institutes and offers scientists optimum working conditions. It also cultivates an international network and aspires to outstanding results by appointing the most qualified researchers available. If an ideal candidate is not available, the appointment is left unfilled.

Scientists from Max Planck Institutes and the Weizmann Institute are currently working together on some 50 joint research projects. The subjects are drawn from every area of the natural sciences (the Weizmann Institute is not engaged in the social sciences). Many of these projects are financed from the EU research budget that supports joint ventures with an international component, such as the interdisciplinary "AnEUploidys" network in system biology and genetic research, in which the MPI for Molecular Genetics is involved. The EU set aside more than 8 million euros for this project for a five-year period ending in 2010.

There is also a regular exchange of scientists working on smaller, bilaterally financed research projects. One such example, in the field of structural molecular biology, is a study of the proteins involved in Alzheimer's disease. Cooperation has traditionally been strong in the field of neurobiology. Nobel laureate Professor Bernd Sakmann, together with colleagues at the Weizmann Institute, is researching the network of nerve cells in the brain and how these cells are stimulated.

The MPI for Nuclear Physics in Heidelberg, whose scientists took part in the very first joint projects with Israel, continues to be involved with the Weizmann Institute in the study of atomic and molecular physics. Prior to his appointment as President of the Weizmann Institute, Professor Daniel Zajfman was a Director at the MPI for Nuclear Physics. It was at that time that he initiated the Cryogenic Storage Ring (CSR), which operates at extremely low energy and temperature levels. The device is intended to help physicists understand chemical-physical processes in space by replicating them in the laboratory.

The Max Planck Society and the Weizmann Institute also have a shared interest in providing support for junior scientists. The International Max Planck Research School at the MPI for Biophysical Chemistry in Göttingen and the Feinberg School (a Weizmann Institute facility for junior scientists) are jointly engaged in training doctoral students.

Over time, the topics of mutual interest have become increasingly interdisciplinary. For example, the "Cell Environments" research project brings together biologists, chemists, materials researchers and nano-scientists, all of whom are focused on the origins of cell growth and behavior, and how these are influenced by their environment. The project involves several institutes on both sides and is seen as a source of great future potential in this field.

Professor Daniel Zajfman, president of the Weizmann Institute of Science.

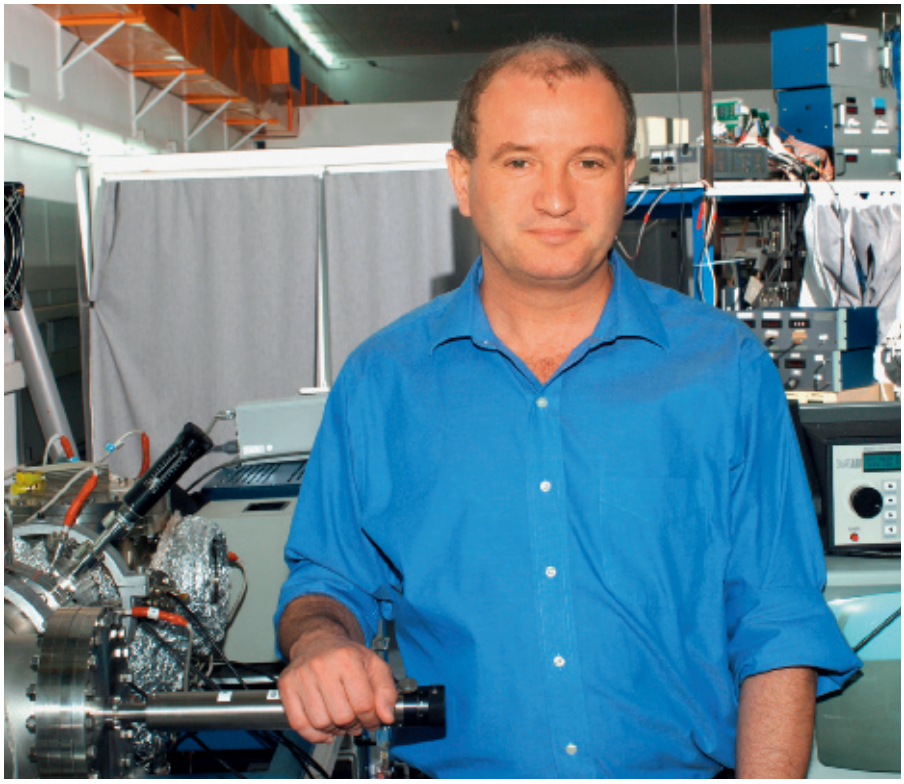

Photo: Weizmann Institute of Science

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- Institute / research center
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- Other research establishments

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- Rome
- Florence

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