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MaxPlanckResearch seeks to keep partners and friends of the Max Planck Society up to date. Four editions of the magazine are published in German each year, all of which are translated into English. At present, the English version has a circulation of 10,000 copies (MaxPlanckForschung: 8,000 copies). It is free of charge. None of the views and opinions expressed in MaxPlanResearch may be interpreted as representing the official views of the Max Planck Society and its associated bodies. MaxPlanckResearch is printed on paper bleached without chlorine. Reprint of texts is permitted if source is quoted. Photographic rights may be granted by agreement.

The Max Planck Society for the Advancement of Science comprises 80 research facilities with some 13,400 staff, including around 4,900 scientists. In addition to this, about 1,000 scholarship holders, guest scientists, and doctoral candidates joined the Max Planck Society in 2008. The annual budget for 2009 is calculated in total at 1,300 million euros. Research activities of the Max Planck Society focus on basic research in natural sciences and the humanities. The Max Planck Society is a non-profit organization registered under private law as an incorporated association. Its central decision-making body is the Senate, with members from the world of politics, the scientific community, and the profession/public, providing for a well-balanced partnership.
Smell and taste, once known as the “lower senses,” long led a shadowy existence in the field of sensory physiology, while sight and hearing, the “higher senses,” basked in the limelight of research. It was only with the advent of molecular biology that the “chemical senses,” as smell and taste are now called, were awakened from their slumbers. Especially the discovery of olfactory receptors by Nobel Prize winners Linda Buck and Richard Axel in 1991 made the sense of smell one of the most exciting fields in neurobiology.

In principle, the chemical senses always follow the same signal chain: a stimulus molecule bonds with a specific receptor integrated into the wall of a sensory cell. This action triggers a cascade effect, generating a neuronal signal that, in turn, is processed by nerve cells along the chain and conducted to the brain. The resulting perception is swiftly followed by recognition, reaction and emotion.

We perceive the scents of flowers and fruit as a pleasant sensation, but are repelled by rancid odors. The close link between smell and taste is an indicator that, in the course of evolution, smells served as signals to keep us safe from substances that might harm us. It is estimated that 70 percent of taste is actually based on olfactory sensations – just consider how food loses its flavor when we suffer from a cold.

However, odors are also important signals when it comes to choosing a partner. The classic experiments with butterflies carried out by Dietrich Schneider and Karl-Ernst Kaißling at the Max Planck Institute for Behavioral Physiology, and the synthesis of pheromones by Adolf Butenandt offer some impressive examples.

As for the issue of “smell,” the Max Plank Society has since dedicated three new departments to this subject. We focus on them in this issue of MAXPLANCKRESEARCH. The group headed by Bill Hansson is using some elegant genetic and optical methods to investigate how odors are processed in the brains of insects. Peter Mombaerts and his staff are studying the sense of smell in mice: how are the thousand or so different olfactory receptors in the mucous membrane of the nose distributed, and how do the nerve pathways in the brain interconnect? Benjamin Kaupp and his department at the caesar research center are addressing the role of smell in choosing a partner at its most elemental level: namely how sperm “sniff out” an egg cell.

Olfactory perception has become a new focal point of biomedical research at the Max Planck Society. The appointment of Gilles Laurent to the Max Planck Institute for Brain Research adds further emphasis to this research path. Laurent is seeking to decipher the code of olfactory perception in the brain.

I hope that this initial “taste” of the olfactory world will enable you to appreciate at least some of the fascination this research holds.

Heinz Wässle, Emeritus Director at the Max Planck Institute for Brain Research
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Mass spectrometry is used to identify chemical compounds. In the MALDI (Matrix-Assisted Laser Desorption/Ionization) process, for instance, proteins are crystallized with the matrix and broken down into small protein ions with laser beams. These are then traced and analyzed. One of the disadvantages of this method is the solid matrices it uses, because, in addition to the ions produced by the laser light from the mix of substances being analyzed, ions with masses of less than 500 daltons also emerge from the matrix. As a result, the many small molecules that play a part in the metabolism of living beings cannot be detected. “The ions from traditional matrices are the haystack in which we are looking for some important needles,” explains Aleš Svatoš, who heads the research group at the Max Planck Institute for Chemical Ecology in Jena.

Together with colleagues from the Czech Academy of Science, his team has now modified the matrices so that they no longer produce disruptive ions. The new method, called matrix-assisted ionization/laser desorption (MAILD), has helped the researchers reliably and quickly identify in excess of 100 different molecules. They also use clinical samples: it is possible to detect a whole range of organic acids that are specific to blood in a single droplet – less than a millionth of a liter. The methods used for these analyses in medical practice are complex and unwieldy. If it were possible not only to determine the presence of the metabolites, but also to quantify them, MAILD might advance to become a method for rapid analysis in biomedicine. As it holds such great potential for diagnostic applications, this process has now been patented.

Carbohydrates located on the shells of pathogens offer the immune system a point of attack and are suitable as vaccines in that they train the immune system to deal with the microbes. The researchers have already identified almost a dozen candidates for vaccines, including one acting against the malaria pathogen, and produced them with the new apparatus.

“Our automatic synthesizing system currently offers an unbeatably fast method of manufacturing complex carbohydrates,” says Peter Seeberger, Director at the Max Planck Institute in Potsdam. “As there used to be no efficient way of doing this, biologists and doctors tended to have a problem with carbohydrates.” In many cases, they even had to give up their work because there was no equipment they could buy that would produce the substances. Finding the situation profoundly irritating, Seeberger decided to do something about it.

He presented his synthesizing device for carbohydrates at the 237th Meeting of the American Chemical Society in Salt Lake City – and received the Claude S. Hudson Prize in Carbohydrate Chemistry from the Society. The device can make complex molecules from linked sugar molecules in just a few hours. The technology that is commonly used now takes months or even years.
A Clear View of Young Planets

When the converted jumbo jet takes off for its first scientific flight in the near future, some of the technology on board will be from Germany: GREAT, the German REceiver for Astronomy at Terahertz frequencies, was developed by a consortium of German research institutions led by Rolf Güsten from the Max Planck Institute for Radio Astronomy in Bonn. Following extensive laboratory testing, the instrument successfully passed the pre-shipment review in early December last year and was taken on board SOFIA for its first deployment. SOFIA is a joint American-German project to operate an aircraft observatory at an altitude of 13 to 14 kilometers. It allows the universe to be examined in infrared light, at wavelengths that cannot be received on the ground because the radiation is absorbed by the water vapor in the Earth’s atmosphere. GREAT will help improve our understanding of the physical processes involved in the formation of young stars and planetary systems.

“Jugend forscht” Winner Meets Nobel Prize Winner

More than 10,000 young people took part in Germany’s 43rd national “Jugend forscht” (youth research) competition, which was held under the motto “Du willst es wissen” (You want to know). Two hundred of them qualified for the final, which was held in Osnabrück. Like every year, the Max Planck Society endowed all five prizes awarded in the Biology category. Nobel laureate Bert Sakmann made a special trip to Osnabrück to present the proud winners with their certificates.

Half-Time for the Science Express

In April of this year, a host of prominent politicians, including Chancellor Angela Merkel and Federal Research Minister Annette Schavan, waved the Science Express off on its journey. The exhibition train has now stopped at 28 stations throughout Germany and filled almost 100,000 visitors with enthusiasm for science and research.

http://www.expedition-zukunft.org

Peter Gruss next to Angela Merkel, with Annette Schavan and Hartmut Mehdorn on the right.

A Question for the President

Why did you study one of the natural sciences?

I owe my enthusiasm for biology to excellent teachers who also challenged me. Particularly in junior high school, we enjoyed exciting and ambitious chemistry and biology lessons with fantastic teachers who also experimented along with us. I can remember one experiment with the fruit fly Drosophila very clearly – but that was a bit later. The experiment was about the smells that attract and repel the fly. I was totally fascinated by the molecular details that lay behind it. I think it is crucial that young people in junior high be so engaged by physics, chemistry or biology that they can imagine studying these subjects at a later stage, because this is usually the age at which the decision is made. The teaching must reflect how dynamic these subjects are – more than it has done up to now. There is always something new to think about when you study the natural sciences. The most fascinating developments can currently be observed in physics and chemistry, and particularly in biology, and all of these areas offer a whole range of exciting jobs and work opportunities.
“The findings of biosafety research must be accepted”

In June, a podium discussion about green genetic engineering was held at the Max Planck House near Munich’s Hofgarten. Afterwards, Bernd Müller-Röber, a professor at the University of Potsdam and also the head of a research group at the Max Planck Institute of Molecular Plant Physiology, answered questions on the status of the genetic engineering debate.

Politicians are currently polarized on the issue. Minister Aigner is not allowing the Bt-Mais Mon 810 maize (corn) plant to be grown, but has authorized cultivation of the genetically altered Amflora potato, at least for experimental purposes. Yet the EU is refusing to grant permission for this. How do you view the political situation at the moment? How much of the debate is still founded in scientific fact?

Bernd Müller-Röber: I find the political situation difficult. And I don’t believe it is always guided by scientifically based fact. Biosafety researchers, including those in Germany, have conducted many tests on Mon 810 in particular, and the results have shown quite clearly that, in many cases, Mon 810 exhibits less genetic variability than other maize plants, and the effects are less pronounced than the variability between different varieties. Furthermore, different locations can also affect the results. Indeed, the influence of the environment and soil on the plant’s composition can be greater than any genetic modification. Biosafety research has received a lot of funding, and rightly so, and now we need to accept the findings. And I personally have a problem with politicians who don’t do that.

And what is the situation with Amflora?

Bernd Müller-Röber: I believe that the problem with the Amflora potato is actually the fact that a marker gene that makes it resistant to antibiotics has been engineered into its genome. It would probably be much less difficult to discuss the Amflora issue if the plant did not contain this gene. However, its use was evaluated many years ago. This is a gene that frequently occurs in bacteria, and thus in any sewage treatment plant and any soil. Seeing this as a new danger is unjustified from a scientific point of view.

The difficulty of the debate about green genetic engineering is undoubtedly also due to the fact that corporations are, of course, pursuing commercial interests. Particularly the patentability of genes or even entire genomes engenders a great deal of resentment in people. Would a greater proportion of publicly funded research whose objective was not first and foremost an economic one help make green genetic engineering more acceptable?

Bernd Müller-Röber: As field trials are extremely complex and require special expertise, particularly for their execution, we have already discussed whether we shouldn’t perhaps create centers across Germany, for example in different climatological areas with different soil types. At these centers, researchers could undertake organized field trials and associated biosafety research, naturally with the aim of evaluating genetically engineered modifications in the field. To win over the public, or at least to arrive at a more neutral basis for discussion, it might be helpful to think about how these field trials could be carried out with the participation of different experts – some who carry out genetic engineering, some who are more involved in environmental research, and some with their eye on the more economic aspects of the plants. When that is publicly funded and an explanation offered to the public, then we might have achieved something.

You mentioned the benefits that green genetic engineering can have for organic farming. However, the point of view in that camp seems to have been elevated to the status of ideology.

Bernd Müller-Röber: Yes, I do think it is a problem that genetic engineering, as a method of changing the genetic information in a plant, is categorically unacceptable in organic farming. As long as this categorical rejection is maintained, organic farming will not accept any genetic modification that might actually have some benefit. But it is not easy to sell the public on the genetically modified plants currently on the market. Just try persuading someone that herbicide-tolerant plants make sense. That’s really difficult. There are two reasons why developments have taken this course in the past: First, it was precisely this kind of genetic modification that was relatively easy to achieve, compared to those that researchers and breeders are trying to accomplish today – such as better nutrient utilization or drought tolerance. And second, the companies backed these first, because it was so easy and because they were most likely to earn money from them.
Herschel and Planck in Space

We have lift off! On May 14, an Ariane 5 rocket transported two satellites, Planck and Herschel, into space. Over the next few years, the two space probes will orbit the Sun at the second Lagrange point, around 1.5 million kilometers from Earth. From this location, Planck will record cosmic background radiation with previously unachieved levels of precision, and the infrared satellite Herschel will look into the hidden universe. While scientists at the Max Planck Institute for Astrophysics developed major software components for Planck, researchers from the Max Planck Institutes for Extraterrestrial Physics, for Astronomy, for Radio Astronomy and for Solar System Research contributed to two of the three scientific instruments on board Herschel. Herschel’s 3.5-meter telescope will scan space at wavelengths between 55 and 672 micrometers. The satellite will first resolve the diffuse cosmic infrared background into its individual sources. Other objectives include remote galaxies, star nurseries and objects within the trans-Neptune region to the limits of our solar system.

On June 14, the scientists had another reason to celebrate: Herschel’s cryostat roof opened and the measuring devices had an uninterrupted view of the universe for the first time. The PACS instrument (Photo-detector Array Camera and Spectrometer) produced the first images, which exceeded every expectation. The subject was the famous Whirlpool Galaxy M 51 in the Canes Venatici constellation around 37 million light years away. The images were taken with the PACS three-band photometer at wavelengths of 160, 100 and 70 micrometers and hint at the huge potential of the new infrared satellite.

Photos: ESA/ESA & The PACS Consortium

A giant eye sees infrared: The European Herschel satellite has arrived in space and scientists are already delighted – it transmitted the first images of the Whirlpool Galaxy in mid-June.
Fire Enhancers within the Financial System

For many people, the explanation of the financial crisis is simple: Blind with greed, bankers gambled on low-quality, subprime mortgages in the United States. A look at the numbers, however, indicates that there is still a puzzle. As of October 2008, the International Monetary Fund (IMF) estimated the total losses on these mortgages at some 500 billion dollars. This figure seems both too low and too high.

TEXT MARTIN HELLWIG

The figure of 500 billion dollars is too low to explain why the global financial system, with bank assets of 80 to 90 trillion dollars, was dragged into the abyss. Back in 1990, the losses incurred by the US savings and loan associations were said to amount to some 600 to 800 billion dollars. In the Japanese banking crisis of the 1990s, the banks’ actual losses amounted to more than 500 billion dollars. In neither case did the crisis have any repercussions for the global financial system as a whole.

At the same time, the figure is too high to be explained by lowered expectations of debt service on subprime mortgages. As of October 2008, the IMF estimated the total volume of non-prime mortgages at some 1,100 billion dollars.

Losses of 500 billion would imply a loss rate of 45 percent. If borrowers initially had, on average, 5 percent equity in their homes, a loss rate of 45 percent on the mortgage would imply a loss rate of 50 percent on the value of the underlying real estate. Between mid-2006 and mid-2008, however, real estate prices in the United States dropped only 19 percent on average, with the worst hit metropolitan areas recording a 33 percent decline.

Admittedly, this back-of-the-envelope calculation is over-simplified, but the main point is that the IMF’s loss estimates refer to market prices of mortgage-backed securities, not to the debt service on the underlying mortgages. The two are not the same and, as the IMF points out, there are good reasons to believe that market values are significantly below present values of expected returns on the underlying mortgages, either from the borrowers’ debt service or from foreclosure proceeds. The fact that market values are too low is due to systemic interdependence. The financial crisis is thus not just a matter of subprime mortgages and gambling bankers. The crisis is also due to some fundamental flaws in the architecture of the international financial system. Indeed, many devices that were supposed to serve as fire extinguishers have in fact worked as fire enhancers, adding yet more fuel to the flames. Part of the blame for this must be given to statutory regulation. In principle, it is a good idea to shift some of the risks of real estate finance to third parties. Problems in real estate markets have always been among the most important causes of financial crises, as was the case in the banking crises of the late 1980s and early 1990s. Real estate finance is problematic because, in terms of economic aggregates, the values involved are high relative to the overall wealth of the economy. Moreover, the economic lifespan of a typical real estate investment extends far beyond the time horizon that the typical saver envisages for his investments.

The discrepancy between the economic lifespan of a real estate investment and the time horizon of the typical saver is a major source of risk. If a real estate investment is financed by short-term loans, the borrower faces the risk that, when these loans come due, he may be unable to refinance the property. If the investment is financed by long-term loans, the financier faces the risk that, if he wants to liquidate his holding prematurely, he may not be able to do so, or the price may be quite low.

Experience has shown that neither the banks nor the mortgage borrowers are well suited to bear these risks. Around 1980, for instance, when refinancing rates had risen to over 15 percent, many savings institutions in the United States were technically insolvent because...
Downward spiral: For many Americans unable to repay their loans, the dream of home ownership has become a nightmare. The problems with private real estate financing triggered a global financial crisis. The origins lay in the architecture of international finance.
the 6 percent they earned on the 40-year fixed-rate mortgages they had issued in the 1960s were far below their refinancing costs. This insolvency was the ultimate cause of the US savings and loan crisis of the 1980s. Much of the interest rate risk of mortgage financing was subsequently passed on to debtors by means of adjustable-rate clauses. However, when market interest rates rose to another high in the late 1980s, many borrowers were unable to cope with the ensuing rate adjustments and defaulted on their debts; the banks that foreclosed on the mortgages then found that, with interest rates high, property values were relatively low.

The securitization of mortgages provides a means to pass risk on to third parties. This makes sense if these third parties are better able to bear the risk. For risks arising from the longevity of real estate finance, this is actually the case: these risks are better placed with life insurers or pension funds because the liabilities of these institutions also have very long-term horizons.

Many borrowers could not cope and defaulted on their mortgage debts.

In principle, it is also a good idea to use the typical securitization procedures of packaging and tranching. If one puts a large number of individual mortgages into a package, the returns on the package do not depend very much on the specific characteristics of any one mortgage. The resulting standardization contributes to making the mortgage-(package-)backed securities tradable. If one divides the returns on such a package into different pieces by issuing different kinds of debt with different priorities against this package, then, ordinarily, the default risk on the senior debt will be low. Selling this debt to a third party will thus not have much of an effect on the issuer’s incentives to assess the credit risks of the underlying mortgages. In contrast, the owner of the so-called equity tranche – that is, the residual returns that are left after all debt has been serviced – is very much affected by the incidence of credit risk on the underlying mortgages and thus has a strong incentive to assess this risk beforehand. If the equity tranche is retained by the initiating mortgage bank, this bank will put a lot of effort into assessing the mortgage borrower’s creditworthiness. This corresponds to the construction of the German Pfandbrief, where the initiating bank is fully liable for the debt it issues, and bears all the credit risk in its mortgage lending. Alternatively, if the bank that performs the securitization takes on the liability for the credit risk of the underlying mortgages, this bank at least has an incentive to impose some quality standards for the mortgages it accepts, and thus to impose some discipline on the initiating mortgage banks.

When mortgage securitization was introduced in the United States, there was no provision to make the mortgage banks liable for credit risks in their mortgage lending. In the beginning, this omission had no further consequences. Fannie Mae and Freddie Mac, the government-sponsored mortgage banks that first introduced large-scale mortgage securitization, provided guarantees for the debt service on the mortgages they securitized. At the same time, they imposed a minimum standard for the quality of the mortgages they would accept for securitization. The term prime mortgages describes mortgages that meet this standard.

After 2000, however, New York investment banks moved aggressively into mortgage securitization. Unlike Fannie Mae and Freddie Mac, these banks did not provide any guarantees for the debt service on the mortgages they securitized. Moreover, they focused on mortgages that did not meet the quality standards of Fannie Mae and Freddie Mac – the so-called subprime mortgages. No attention was paid to the incentive implications of the fact that, now, neither the mortgage banks nor the securitizing institutions bore any liability for the credit risk of the underlying mortgages. The investment bankers seem to have known all about market risks and nothing about credit risks.

Subprime mortgage lending and securitization grew rapidly in importance. By 2006, these mortgages accounted for more than 40 percent of new mortgage lending (2000: 9 percent) and 14 percent of the overall stock of outstanding mortgages (2000: 7 percent). Their quality declined steadily. Up to 2006, however, the quality deterioration was masked by the rise in property prices. These prices grew about 9 percent per year from 1999 to 2003, and about 15 percent per year from 2003 to 2005. The leap from 9 to 15 percent in 2003 coincided with a massive expansion of private investment bank activity in mortgage securitization.

The expansion was fuelled by expansionary monetary policy. In the years from 2002 to 2004, money market interest rates in the US were between 1 and 2 percent, compared with 6 percent in 2000 and 4 percent in 2001. Long-term interest rates on government securities dropped from 6 percent in 2000 to just over 4 percent in 2003 to 2005, and interest rates on fixed-rate prime mortgages from 8 percent in 2000 to just under 6 percent in 2003 to 2005. The difference between this mortgage rate and the money market rate thus actually rose from 2 percentage points in 2000 to 4 percent between 2003 and 2004.

Investors buying the mortgage-backed securities do not seem to have exerted any “market discipline” that might have compensated for the lack of liability on the side of the mortgage-initiating and mortgage-securitiz-
ing institutions. Whereas the quality of mortgage debtors was steadily going down, risk premiums for fixed-rate subprime mortgages dropped from 3 percent in 2001 to 1 percent in 2004. In contrast, there was no such change in the risk premiums for corporate bonds in these years. Investors in mortgage-backed securities seem to have focused on yields without paying much attention to risks. Among these investors, three groups are noteworthy:

First, hedge funds and investment banks bought the equity tranches; the fact that, for incentive reasons, mortgage initiating and mortgage securitizing banks should have retained these tranches was ignored. Second, other investment banks bought subordinated debt, the so-called mezzanine tranches, and securitized them again by forming packages and issuing different debt instruments against these packages. Finally, so-called conduits and special-investment vehicles (SIVs) created by European and American banks bought all sorts of mortgage-backed securities, refinancing themselves by issuing asset-backed commercial paper, or very short-term securities; these vehicles had practically no equity.

Investors seem to have paid attention only to yields, ignoring issues of risk as well as incentives. They relied on the rating agencies’ assessments – without questioning whether a “AAA” rating on one security could really mean the same thing as a AAA rating on another when the interest rate was significantly higher for the first security than for the second.

But the assessments of the rating agencies were seriously flawed. These agencies exaggerated the effects of diversification across securities, neglecting correlations arising from the dependence of different risks on common underlying factors such as movements in market rates of interest or movements in real estate prices. They also seem to have believed that real estate prices could only go up, and that credit risk on the underlying mortgages was thus negligible. They failed to appreciate that at least some of the observed increases in real estate prices were due to one-time changes in the environment that would not be repeated, such as the decline of interest rates from 2000 to 2003, or the influx of funds into mortgage finance that was caused by the innovation of subprime mortgage securitization.

In 2005, monetary policy became more restrictive, and by 2006, short-term interest rates had gone up to 5 percent again. In mid-2006, real estate prices began to fall and the problems of subprime mortgages came out into the open. In April 2007, these problems were fully understood – and clearly explained in the IMF’s Global Financial Stability Report. Remarkably, however, this analysis by the IMF concluded with the assessment that there was only a small probability of the subprime mortgage crisis spilling over and upsetting the rest of the financial system.

Precisely such a spillover came in August 2007: The rating agencies downgraded mortgage-backed securities, some by as much as three grades at once. This caused a fall in the market prices of these securities. The conduits and SIVs that held such securities had no equity to buffer their losses and became de facto insolvent. Financing for these companies from the money market collapsed and they had to call on the sponsoring banks to make good on the promises of liquidity assistance that they had previously given. Some of the sponsoring banks were unable to meet these demands and became insolvent themselves. On the whole, the liquidity assistance from sponsoring banks was not sufficient to fully replace the vanished financing from the money markets.

Malfunctioning markets

There were thus two shocks that markets had to absorb: first, the drastic downgrading of mortgage-backed securities by the rating agencies, and second, the sudden breakdown of the mechanisms by which SIVs had financed their holdings of mortgage-backed securities. The importance of these “shadow banks,” on the order of 1,000 billion dollars, took everybody by surprise.

These two shocks triggered a downward spiral of the financial system that went unchecked until October 2008. This downward spiral is characterized by the interaction of the following elements: First, many markets were not functioning properly. Asset prices fell drastically but, even so, there were few buyers. Many investors feel vulnerable with respect to their own financing and do not want to enter into new commitments; many investors expect prices to fall even further, and many also fear that, in terms of the selection of assets offered for sale, they may be taken advantage of by the sellers.

Second, under fair value accounting for market risks, the banks are obliged to immediately adjust the values at which they carry these securities on their balance sheets. The resulting write-offs diminish the banks’ equity.

Third, most banks had virtually no equity capital in excess of regulatory requirements. In order not to fall afoul of regulatory requirements, they had to react immediately to the write-offs, either by raising new capital or by selling assets. Raising new equity is difficult in a crisis. Selling assets, however – deleveraging – puts additional downward pressure on market prices.
Beyond the lack of “free” equity capital, many banks in fact had very little equity capital at all, and the write-offs that they had to take soon raised questions about their solvency. Under the so-called model-based approach to capital regulation, the required capital of a bank is determined on the basis of the bank’s own quantitative risk model. The banks used this regulatory scheme to “economize” on equity – more precisely, to expand the activities supported by the equity they had. At UBS for example, before the crisis, equity accounted for 2.5 percent of the balance sheet total, or 40 billion out of 1,600 billion Swiss francs. The bank’s losses on mortgage-backed securities have been substantially higher. If it hadn’t received new equity capital from the Government of Singapore Investment Corporation and the Swiss Confederation, UBS would long since have been declared insolvent.

As doubts about solvency grew, banks became less and less willing to lend to each other, and interbank markets ceased to function properly. This created additional problems for US investment banks that had been accustomed to financing themselves through short-term money-market instruments that had to be continually rolled over. For Bear Stearns, this method of financing dried up in March 2008. Lehman Brothers suffered a similar fate in September.

Doubts about solvency made banks less and less willing to lend to one another.

To alleviate doubts about their solvency, many banks tried to improve their equity positions – by deleveraging. Fears about their ability to refinance thus had a similar effect as capital regulation, inducing banks to sell assets in order to maintain their equity ratios. Fourth, deleveraging added to the downward pressure on market prices of securities. The resulting price declines forced further write-offs and further deleveraging from other banks, with yet further repercussions for prices and write-offs. This downward spiral characterized developments from August 2007 to September 2008. On several occasions, liquidity injections by central banks relieved acute crises. These injections, however, could not actually stop the downward spiral. At last, with the insolvenzy of Lehman Brothers in September 2008, the financial system imploded altogether and was kept working only by government subsidies and guarantees. These interventions seem to have stopped the downward spiral, at least for the time being.

As yet, it is impossible to say what comes next. The real economy turned down only in the last quarter of 2008. This downturn will impair the debt service of nonfinancial firms to the banks, which will further damage the banks. If this induces another round of deleveraging, there is a risk of a new downward spiral, this time in the interaction between the banks and the real economy.

The questions raised at the beginning of this article regarding the estimated 500 billion dollar losses on securitized subprime mortgages can now be answered: declines in securities prices were higher than the declines in present values of expected returns because securities markets were not functioning well. The effects on the financial system were greater than in other crises because the interaction of price declines, fair value accounting, lack of equity, and deleveraging acted as fire enhancers.

In thinking about causes and responsibility, one must distinguish between misbehavior and flaws in the system. Misbehavior is a behavior that ultimately works against the person or institution in question. Flaws in the system are flaws in the rules and institutions that govern individual behavior such that, if individuals abide by the rules – while pursuing their own self-interests, the results are detrimental for the institutions involved, or even for the financial system as a whole. For flaws in the system, the question of who is responsible is of a different character than for individual misbehavior.

Individual misbehavior: Investment bankers were so focused on sales growth and market shares in mortgage securitization that they neglected the risks of this business. Investors of all sorts were so focused on yields that they neglected the risks that come with higher yields. Large banks combined an active stance in mortgage securitization with holdings of mortgage-backed securities on their own account without analyzing the risks that this combination implied. The rating agencies likewise had no adequate model of the relevant risks.

Another form of misbehavior involved the excessive practice of “borrowing short to lend long,” by the SIVs of the German state banks (Landesbanken), as well as US investment banks, without concern for refinancing risks. Monetary policy induced short-term interest rates to be very low and yield curves to be very steep in the years 2002 to 2004, and thus made the practice of “borrowing short to lend long” even more tempting than usual.

Flaws in the system: The fact that banks involved in initiating or securitizing mortgages bore no liability for the credit risk of these mortgages was a major reason for the drastic deterioration in the quality of mortgage borrowers. The effect was reinforced by a lack of quality control from yield-hungry buyers. European invest-
ment banks keen on securitizing mezzanine tranches created an uncritical demand for these securities — though, economically, such further rounds of securitization served no useful purpose.

German public banks had no sustainable business model and were “gambling for survival” — without any regulatory intervention. Like US investment banks, the conduits and SIVs of these institutions were outside the domain of statutory supervision, so no one had any idea of the magnitude of their overall commitments and of the extent of maturity transformation they had engaged in. At private banks, both internal and external risk management and control systems failed: Internally, there was a failure of risk control over investment banking. Externally, there was a failure of market discipline by shareholders, analysts and the media, all of whom paid more attention to returns than to risks. Yet a 25 percent rate of return on equity, taken as a benchmark in banking, must involve a risk premium, most likely reflecting the risks stemming from the bank’s being undercapitalized.

Bank risk management was based on the assumption that, through their quantitative risk models and stress tests, they had all important risks under control. Some risks, however, cannot be adequately captured by such models. Thus, it is practically impossible to obtain reliable estimates of correlations between the credit risks on different mortgages and different mortgage-backed securities, or of the correlations between the counterparty risks in a hedge and the underlying risk against which the hedge is taken — or of the risks of systemic repercussions emanating from the maturity transformation of conduits and SIVs.

The accusation that too little account was taken of the inadequacies of quantitative risk models can also be leveled against the supervisory authorities. Since 1996, their rules have permitted banks to determine their capital requirements for certain risks exclusively on the basis of risk models. This is why some banks were able to expand their operations so that their balance sheets totaled 30, 40, or even 60 times their equity. “Ten percent core capital” doesn’t mean 10 percent of the balance sheet total, it means 10 percent of risk-weighted assets, with risks based on the bank’s risk model.

The model-based approach to capital regulation was introduced in the 1990s after a long process of “regulatory capture.” The banks insisted that equity requirements had to be adapted to risks and that their own risk models provided the proper basis for doing so. Faced with the expertise of the banks, the regulators gave in. In the process, however, very little was said about the effects such regulation would actually have on risks in banking, or about the difference between the public interest in financial stability and the private interests of the bank.

If equity requirements had been higher overall, and if there had been a less mechanical approach to applying the regulation in the crisis, there would have been less need for deleveraging, and doubts about solvency would have been less urgent. But bank regulators and supervisors can be criticized for not thinking in systemic terms. They focus on the solvency of individual institutions and the need to protect investors in these institutions, without realizing that the survival of these institutions depends on the systemic environment. The lack of reporting duties for hedge funds, conduits and SIVs can be defended if one thinks only about investor protection, but not if one thinks about the systemic implications for other financial institutions. The requirement to deleverage by selling assets if write-offs erode a bank’s equity can endanger the bank itself if the systemic repercussions on prices and on other institutions induce further declines in the value of the bank’s remaining assets.

At this point, there is widespread agreement that financial regulation must be extended and strengthened. To date, however, there is little appreciation of the fact that the current system of banking regulation has itself contributed a lot to the downward spiral in the crisis. It is thus necessary to rethink the conceptual basis of this system.
Producing offspring is not always easy. This is especially true when your home is located underwater and the neighbors – a bizarre mix of phlegmatic relatives and agile, greedy finned creatures – are constantly passing through your living space. Invertebrate sea urchins are at a particular disadvantage. Sex is not a realistic option for a creature with a calcareous exoskeleton comprising hundreds of prickly needles. Fertilization? Yes, but only outside the body!

Once a year sea urchins gather together on the sea floor, often in groups of up to 30 individuals, for the purpose of reproduction. They huddle together and release egg cells and sperm at depths of up to 40 meters, depending on the species. This cooperation increases their chances of success, as their reproduction efforts are frequently thwarted by the ocean current, fish and other marine creatures swimming by in their search for protein-rich snacks. There are no half measures here: a male sea urchin releases around 100 billion sperm – as compared with the paltry 200 million produced by the human male – and the female releases 50,000 eggs.

The really astonishing thing is that, despite the fact that different species of sea urchins, snails, fish and other cohabitants of the biotope also engage in extracorporeal reproduction, no accidental hybrid creatures ever arise. No “starfish urchins,” no “urchin snails,” no “fish urchins” – not even hybrids of the approximately 900 species of sea urchins. No, the sea urchin sperm find their way unerringly to the egg cells of their own species. It almost seems to happen by magic. But the magic here is chemotaxis.

Chemotaxis can be more or less defined as “movement in the direction of a chemical substance.” And that is precisely what happens: hungry bacteria and amoeba also use the technique, zigzagging toward their food sources like sniffing dogs. This process is referred to as a “random walk”. So what about the sea urchin sperm? They follow the trail of an attractant transmitted by the egg cell. The male gametes, which are 50 to 60 micrometers long, actively swim – in a pattern somewhat akin to a bent helix – in the direction of the increasing concentration of attractant. It all sounds fairly straightforward, just a question of following their noses. The reality, however, is not quite so simple.
Benjamin Kaupp and his team at the caesar research institute in Bonn are studying how this process works in detail. Molecular sensory systems is the general term used to describe the area in which Kaupp works, and it is also the title of his department. For more than 30 years, the biophysicist has been researching how sensory cells register and respond to stimuli in sensory processes, such as seeing, smelling and, in the case of sperm, chemotaxis. Despite being very different in many respects, these three processes have much in common. Each sensory cell transforms stimuli into electrical signals via a chain of biological reactions. Ion channels, which usually consist of several large proteins, play a key role in this process.

ATTRACTANT RECEPTORS ON THEIR TAILS

The scientists in Bonn are particularly interested in what are known as cyclic nucleotide-gated channels (CNG channels) and pacemaker channels (HCN channels). CNG channels are found, for example, in the membrane of the highly sensitive rod cells in the human retina. “Following the absorption of a single photon, hundreds of ion channels in the cell membrane close,” says Kaupp, who decoded the molecular structure of the CNG channels and discovered that these channels play a significant role in color-blindness. In the 1990s, similar ion channels were also found in the visual cells, known as cones, and in the fine hairs of the olfactory cells.

It was in 1997, while they were searching for channels in other forms of tissue, that Kaupp’s research group stumbled upon strange channels in the sperm of the sea urchin Strongylocentrotus purpuratus. These channels behaved just like those that control the heart beat and rhythmic activity of nerve cells in mammals – true pacemaker channels. The question was, what on earth were they doing in sperm? Are they a valuable tool that is used only for special purposes – possibly chemotaxis in this case?

This was reason enough to take a closer look at the sea urchin sperm and explore the question of which sensory organ they actually use to recognize their attractant. After all, these sperm are not intelligent creatures: they have no real nose, not to mention nerve cells that could transmit sensory stimuli to the brain, which, of course, they lack in the first place. Their heads contain only genetic information relating to their species. Their raison d’être consists solely in conveying this information to the egg cell. Yet their tail, the flagellum, contains over a million receptors for the attractant – so their nose is actually located in their “feet.”
The obvious question here is why such a crucial stage in the reproductive process is being examined using the sea urchin. “There are historical reasons for this,” explains Kaupp’s colleague Timo Strünker. “As it happens, the sea urchin is the species in which sperm chemotaxis was first discovered some 100 years ago.” Working at the Marine Biological Laboratory in Woods Hole on the east coast of the US, Frank R. Lillie observed something strange, which he published in the journal Science in October 1912: when he put a few drops of sea water containing unfertilized egg cells of the sea urchin Arbacia punctulata in with sperm of the same species, he noted that the sperm agglutinated so much that it was visible to the naked eye.

Lillie believed that this occurred because the egg cells had previously deposited something in the water that he called agglutinin. Decades later, it was discovered that the substance involved here was a peptide consisting of 14 amino acids. It is now known that all sea urchin species, all starfish and probably all species of marine animals that spawn have their very own agglutinin.

Of course human reproduction doesn’t involve this chaotic tumult of sperm originating from different species. Apart from the exceptional cases of in-vitro fertilization, the process takes place inside the body. So is chemotaxis required at all in this case? “It would appear that it is, but only in a narrow band around the egg,” says Strünker, “for precision control in the final few millimeters, so to speak.” But more on that later.

Back to the sea urchin. Tracking down the complete biochemical mechanism behind the chemotaxis of Arbacia called for a few tricks, ingenuity and the cooperation of physicists, chemists and biologists. The little peptide is now being produced artificially by chemist Michael Beyermann at the Leibniz Institute for Molecular Pharmacology (FMP) in Berlin. Once he has cleaned it up, his colleague Volker Hagen provides it with a “disguise” – a small protective group of chemicals that renders the peptide biologically inactive, but that can be split easily by a flash of UV light. The researchers call this a caged compound.

The peptide, now fixed in the chemical cage, is mixed with sea urchin sperm in a shallow measuring chamber and observed under a microscope at the caesar institute. The sperm – which can be identified by their light-colored heads – still swim more or less randomly around their swimming pool. Unlike in the sea, in the shallow cuvette, they simply paddle around in circles, which makes it easier to observe them. The chamber is then exposed to a UV flash through a striped, dotted or “Micky Mouse” mask – the researchers give their playful instincts free rein here. The “disguises” fall off and the attractant becomes active.

The sperm move fast as lightning toward the artificial attractant source and thus form the pattern shown on...
The sea urchin sperm find their way unerringly to the egg cells of their own species. It almost seems to happen by magic. But the magic here is chemotaxis.

The attractant receptor in the sperm membrane, the enzyme guanylyl cyclase, was already known. The signaling pathway that causes the change in the swimming behavior was explained by Kaupp’s team: if an attractant molecule binds to the receptor, the aforementioned enzyme transforms GTP (guanosine triphosphate) into the intracellular messenger substance cGMP (cyclic guanosine monophosphate). According to Kaupp, cGMP is also the messenger in visual cells. The cGMP opens potassium channels (CNGK), through which positively charged potassium ions flow from the cell. As a result, the cell interior becomes more negatively charged and the membrane potential decreases; this means that the membrane is hyperpolarized. This, in turn, results in the opening of the above-mentioned pacemaker channels. “These pacemaker channels are responsible for the rhythmic contractions in the heart muscle,” Kaupp mentions. Potassium then flows into the cell and the membrane potential increases again. The opening of the calcium channels associated with this depolarization ultimately allows the influx of calcium ions, as a result of which the beating pattern of the flagellum changes, and with it, the swimming trajectory of the sperm.

As the researchers established, sperm even react to single molecules of attractant. A single activated receptor is enough. Demonstrating this was no easy task, involving step-by-step experiments and control tests. “It would not have been possible at all without the optical switches, including the caged signaling substances,” stresses Timo Strünker.

So how does all of this work in humans? “We still don’t know very much about that. What we do know is that many elements of the process are different,” says Strünker. This starts with the fact that human sperm do not swim on a helix trajectory, but in a straight line. Their swimming also appears to involve more of a gliding movement along a surface – the epithelium of the fallopian tube – so they swim through a viscous medium, which is not comparable to swimming in sea water. Moreover, in humans, only 10 to 20 percent of the ejaculated sperm are even in a position to reach the egg cell. This makes it difficult to observe them. But human sperm are also “attracted.” If follicular fluid is dropped into a solution containing human sperm, they swim toward it. “But no one has yet succeeded in identifying receptors, intracellular signaling substances or an attractant.” Some researchers believe that the process is more likely to involve thermotaxis than chemotaxis, as there is a temperature difference of between 1.6 and 1.8 degrees Celsius in the fallopian tube.

STEROID HORMONE AS A POTENTIAL ATTRACTANT

But do human sperm not follow bourgeonal, the scent of Lily of the Valley, as claimed by the biologist Hanns Hatt from Bochum? Kaupp shakes his head: “From what we know of the sea urchin, we doubt it. What is certain is that, in both species, the motility of the sperm is controlled by a change in the calcium concentration.” In the experiments carried out using bourgeonal, the human sperm were exposed to a concentration of a few micromoles of the odorant per liter (1 micromole = 1 millionth of a mole). However, the sea urchin sperm react to concentrations in the femtomolar range (1 billionth of a mole per liter). Moreover, the team in Bochum didn’t test whether bourgeonal triggers the formation of the expected intracellular messenger substance. The researchers at caesar did test this and nothing happened.

A Japanese group also discovered that a different odorant is responsible for the reaction in mice. Kaupp has his doubts about both studies. “Because there are numerous substances that cause calcium changes in sperm, we sus-
caesar, which was previously located in temporary facilities in Bonn’s city center, moved to a newly constructed building in Bonn-Plittersdorf in 2003. The three-part complex can house not only three research departments, but also up to eight junior research groups and spin-offs.

In 2006, the Foundation Board passed a resolution in favor of focusing scientific research on neuroscience, and forging a link between caesar and the Max Planck Society while retaining its mission and structure as a legally independent foundation.

The appointment of directors, the evaluation of research and the pursuit of scientific excellence are based on the criteria of the Max Planck Society.

Professor Benjamin Kaupp, Scientific Director of caesar since 2008, is head of the department of Molecular Sensory Systems. He is also a Scientific Member of the Max Planck Institute for Neurological Research in Cologne. Departments of Neurodegeneration and Neurophotonics are currently being established at caesar.

www.caesar.de
above  A clear view of chaos: Benjamin Kaupp and Timo Strünker observe antibody colorings of pacemaker ion channels in brain sections. Such channels are also found in sperm.

below  Noses in their "feet": The receptors for the chemoattractant in sea urchin sperm, here as seen under the optical microscope, are located on the flagellum.
pect that they are all lipophilic, or fat-soluble, compounds that can enter the membrane directly. The observations may well be experimental artifacts.”

So then what does attract human sperm? “There are a few possible candidates.” Kaupp remains rather circumspect. “It is thought that it might be progesterone.” It has been proven that the cumulus cells of the ovum release this steroid hormone. Progesterone normally regulates protein synthesis, and this takes anywhere from minutes to days. But mature sperm do not produce any proteins – why should they? Progesterone can also have a rapid effect: sperm react to it with an intracellular calcium signal within seconds. “We are currently carrying out tests with caged progesterone,” reveals Kaupp.

THE WEAKNESS IN THE FERTILITY TEST

Given that this is so complicated in humans, does it perhaps work on other mammalian models? “Yes, rats, mice and rabbits. We used to work with rabbits,” says Kaupp. Now, however, research is carried out on fresh human sperm at the caesar institute. The institute has built up a small network of volunteer donors for this purpose. Some scientists claim that the attractants in humans, rabbits and mice are identical.

“It is known that the human female’s follicular fluid also attracts rabbit sperm,” confirms Kaupp. “There is a certain logic to that: the sea urchin releases its gametes into the sea and abandons them to their fate. Chemotaxis plays a crucially important role there. In mammals, sexual intercourse precedes the release of sperm, so there seems to be no need for specificity of recognition via the attractant.” This phenomenon is exploited in the so-called hamster test, which checks the fertilization potential of human sperm: the ability of human sperm to penetrate into the egg cells of a hamster is seen as an indicator of healthy sperm function.

Timo Strünker has his doubts, though, as the test has a weak point. Sperm of knock-out mice lacking a calcium channel that occurs only in sperm are active but infertile. Their sperm cannot penetrate the egg membrane. “In the hamster test, however, the egg membrane is removed in advance. And today we know that there are people who have a defect in this channel.”

The potential application that could eventually arise from the basic research being carried out at caesar is clear. It could be used to help couples with fertility problems – on a diagnostic and perhaps even a therapeutic level. Certain ion channels, pumps and transporters are found only in sperm. These proteins are ideal targets for selective contraceptives. The “pill” for men, at last! Of course, there would also be a use for technical sensors that could identify individual molecules in a mixture containing trillions of other molecules. What excites Benjamin Kaupp about his work, however, is something entirely different: the evolutionary links. “Smelling, seeing, chemotaxis in sperm – for me, these are variations on a theme. How was that theme transformed to fulfill such different functions?”

DINING ON LOBSTER MAKES UP FOR WORKING IN THE DARK

The team is currently preparing for another trip to the east coast of the US. Measuring devices are being packed and shipped, the intention being – as every summer – to work with many other researchers from all over the world in the legendary Woods Hole Marine Biological Laboratory, which was established in 1888. Their trip takes them back to the roots of their subject, to Cape Cod, where chemotaxis was discovered in the sea urchin.

It must be wonderful to work in such a beautiful location. Timo Strünker dismisses this suggestion with a wave of his hand: “Well, we don’t see very much of that. Because the caged compounds are extremely sensitive to light, we spend hours working in the dark.” But there is no need to feel too sorry for the scientists. To compensate, they have freshly caught lobster for dinner, not to mention a magnificent view of the vast ocean, whose strange inhabitants still remain largely unexplored.
The fruit fly (*Drosophila melanogaster*) provides a model for the researchers working on olfactory research with Bill Hansson.
Olfactory Research
Is a Precision Business

Have you ever wondered how fruit flies manage to zoom in on a fruit bowl or glass of smooth red wine in the blink of an eye? Although their test subject measures little more than half a millimeter, a research team working with Bill Hansson at the Max Planck Institute for Chemical Ecology in Jena is hot on the scent of the tiny fly’s olfactory system with the help of some highly sophisticated measurement technologies.

TEXT MARCUS ANHÄUSER

The life of the basic researcher is not an easy one. At the meeting of Nobel laureates in Lindau in 1951, the wife of one of the scientists asked the famous pheromone researcher Adolf Butenandt how she could get hold of these “sex-attractant substances” he was working on. When Butenandt explained that he had studied the pheromones of butterflies, the lady replied with disappointment: “Oh, Dr. Butenandt, why did you waste your time with butterflies?”

One can only imagine what this woman would have said to Bill Hansson. The Director of the Department of Evolutionary Neuroethology in Jena is not “wasting” his time working on butterflies, but on even less impressive flies with a penchant for rotten fruit. These pests, which can be found in every fruit bowl in summer, are commonly known as fruit flies or vinegar flies. The fly, sometimes also referred to as the laboratory researchers’ pet, is probably also the only creature whose Latin name, Drosophila melanogaster, is almost as well known as its common one.

Bill Hansson, who is Swedish by birth, has been studying this small insect’s sense of smell for a total of nine years, and since 2006 at the Max Planck Institute for Chemical Ecology in Jena. The decision to focus on this test subject is, of course, no coincidence: “No other animal offers us so many possibilities as Drosophila,” says Hansson. The fly can be modified genetically and therefore manipulated like a model kit: “You can remove building blocks, reshape building blocks, or exchange a red block for a blue one,” says the Max Planck Director, somewhat oversimplifying the processes involved.

ODOR COMPASS WITH KNOBBY SNOUTS

It must be said that, at first glance, the fly does not seem to be a particularly ideal subject for researching olfaction, compared, for example, with the silk moth, the laboratory animal traditionally used in pheromone research. The fruit fly is smaller and its behavior is not as effusive as that of the moth: “When a male moth smells a single molecule of the female’s attractant, whoosh, it’s off and nothing else matters,” says Hansson. In Drosophila, the reaction tends to be less “clear” for various reasons, including the fact that pheromones don’t play any major role for flies over great distances.

This difference can also be observed in the olfactory organs of the two species. The male moth’s finely forked and – relative to the size of the insect – large antennae sit enthroned on the animal’s head like a cross between fern and antlers and demonstrate with impressive clarity the significant role played by olfaction in the moth’s sex life. The corresponding organ in Drosophila takes the form of two conical knobs that sit between the comparatively enormous compound eyes. The term olfactory bulb couldn’t be more appropriate. Somewhat lower down, just above the proboscis, sit two other small knobs, the maxillary palps, which are also used for smelling.

Hundreds of fine olfactory hairs, the sensilla, sprout from the antennae and maxillary palps. An odorant molecule must make its way into these hairs to be recognized. “In principle, each olfactory hair functions like a miniature...
nose,” says Hansson. The odorant molecules submerge into a protein-containing solution, the sensillum lymph, through pores – insects have an otherwise impermeable exoskeleton. The molecules are received in the sensillum lymph by odor-binding proteins that accompany them to their final destination: the olfactory receptors.

DEDICATED LINE TO THE OLFACTORY CENTER

The odorant molecule docks at a receptor, which sits on one of the one to three dendrites, the extended arms of a nerve cell. There, the message “odorant molecule docked” is transformed into an electrical signal. The signal migrates across the nerve cell’s dedicated line, the axon, directly into the fly’s olfactory center. “Just as in humans and all other animals, the olfactory receptors are the only peripheral receptors that conduct signals directly to the brain,” says Hansson.

Hansson’s team needs an entire arsenal of microscopes to be able to study all of this process in the tiny flies. There is hardly a room in the laboratory that doesn’t have one of the high-tech devices, and anyone who wanders through the laboratory will see that these microscopes have little in common with the traditional ones we all remember from our school days. The day of the simple optical microscope is long gone; every possible technical option is now used to push the old system to the limit, increase the resolution or make only certain areas of the object visible. The names – confocal laser scanning microscopes, multi-photon laser scanning microscopes, fluorescence microscopes and inverse microscopes – merely hint at how it all works.

NOT ALL MOLECULES IN AN ODOR EXCITE NEURONS

Various devices are stacked up to the left and right of each microscope workstation. Hansson stops at one of them: “This is our specialty,” he says. The object in question is a gas chromatograph, a device that splits a smell into its molecular components and analyzes them. The chromatograph prints the result on paper as an odor curve that shows the peak values for each individual component. The device also blows the odorant molecule directly at the fly in a gentle stream of air.

The researchers record in real time under the microscope how the flies – or, more precisely, their receptor-equipped nerve cells – react to the smell. Each microscope table has a computer and a monitor beside it. “We combine the odor analysis with the spectra of neuronal activity and allow the antennae to tell us, so to speak, which of the hundreds of molecules transmitted by a banana actually work on the fly,” says Hansson.

Silke Sachse, head of the Optical Imaging Research Group, literally observes the flies as they smell. In order to obtain focused images of a live animal the size of an apple seed, she clamps the animal to a 3-millimeter-wide copper slide. Sachse pushes the
narrow part of the fly between the head and chest into a 0.1-millimeter-wide gap in the slide, making it look as though it were wearing an oversized neck brace. She secures the head in place with a little wax. The animal must be kept completely still to ensure that the microscope images are not blurred. The Max Planck scientist then pushes the slide under the microscope lens. A video camera records the image, enlarged by a factor of between 100 and 400, which can then be examined in comfort on the computer screen.

A MUTANT AS A TEXTBOOK EXAMPLE

For her tests, the biologist uses a mutant fly in which the olfactory process in the antennae, palps and brain can be made visible almost by magic with the help of a dye: “This transgenic *Drosophila* produces a fluorescing dye that colors all of the olfactory sensory neurons,” explains Sachse. Nothing special can be seen here in normal light conditions. However, as soon as the scientist switches to fluorescence, the window becomes dark and the antennae and palps glow neon green. “We can measure through the cuticle,” says Sachse. The dye shines so brightly that it shows through the paper-thin exoskeleton of the olfactory bulbs.

It is not quite so easy to observe the olfactory brain. “To do this, we cut open a window in the head cavity,” explains Sachse. And all that in micrometer-sized dimensions. *Drosophila’s* brain is just a little more than half a millimeter across, an antennal lobe is one tenth of a millimeter, and a glomerulus is ten times smaller. “It really is incredibly small.” Even after many years of research, Silke Sachse is still awed by the dimensions in which she works.

When there is something to be smelled, the olfactory brain also glows bright green. But the dye, which is called chameleon, can do much more – it can indicate changes: “The dye binds calcium. The more calcium it binds, the brighter the antennal lobe glows,” says Sachse. The greater the stimulus to a nerve cell, the more calcium ions stream into the cell. The more calcium streams into the cell, the better it binds with the dye and the brighter the cell glows in the fluorescent light.

GREEN SHEET LIGHTNING OVER THE OLFACTORY BRAIN

The entire process as seen in the film of the recording is reminiscent of sheet lightning erupting over the olfactory brain: a brief flash here, a garish glint there, depending on which odorant molecule the antenna receive. In this way, Sachse obtains activity patterns that are typical for every smell and that can be matched up with the peaks in the olfactory curve: “I can now see exactly which neurons are active with which smell and how strongly activated they are.” She extracts individual shots from the short films and transposes the activity into other colors: red for intense activity, green for average activity and blue for no activity.

While Silke Sachse observes and analyzes the olfactory system of the fly without ever touching it, her colleague
Dieter Wicher penetrates to even smaller dimensions. He works his way through to where the odorant molecule comes into contact with the fly: the olfactory receptors in the sensilla of the antenna. “This is particularly interesting because insects are known for their ability to perceive odorants in very small concentrations,” says Wicher. The fruit fly needs only ten or a hundred molecules in a cubic centimeter of air to sniff something out. “That is a million times more sensitive than the human sense of smell,” says Hansson: “We usually need a few hundred million molecules or more to actually smell something.”

The extreme sensitivity of the insect nose is partly explained by the structure of the receptors and the way in which they transmit the “odorant molecule arrived” signal. Wicher and his fellow scientists identified a previously unknown receptor type using the patch-clamp method: using pipettes, which act as electrodes and whose finely polished tips have an internal diameter of just one hundredth of a millimeter – a human hair is five to ten times thicker – the researchers measure the current flowing through individual ion channels in the range of billionths of amps directly on the nerve cell. Hansson, Wicher and their colleagues presented their findings in the journal Nature in April 2008.

The receptor usually transmits the signal in a multi-phase process via so-called G proteins located on the inside of the cell membrane. At the end, the messenger substance cAMP (cyclic adenosine monophosphate) pours into the cell. This transmits the signal on to ion channels located in a different part of the membrane. But this takes time. The channels open up, eventually developing an electrical potential with calcium, sodium and potassium ions. From there, the information is transmitted electrically as far as the olfactory brain.

Wicher and his colleagues discovered that the receptor and ion channel in the membrane of the insect neurons are immediate neighbors and are not distributed across the membrane as is the case in humans. In insects, they form a two-part entity known as a dimer. “We already knew that this was a dimer, but the fact that the second protein was the ion channel is something our measurements proved for the first time,” says Wicher.

INSECT RECEPTORS ARE DESIGNED DIFFERENTLY

The immediate proximity of the receptor and channel offers key advantages: the signal can take a shortcut. Instead of taking the long route via G protein and cAMP production, the receptor and ion channel can short-circuit. They do this if large concentrations of the odorant molecule flood the receptor. However, if the odor trail is weak, the receptor switches to the traditional biochemical path via G protein and cAMP messenger substance, an option that is still shorter than it is in the mammalian cell. “Stimulus transduction in insects is thus a far more sensitive process than that involving the olfactory receptors of other animals,” explains Wicher.
The researchers still do not fully understand the system. A number of questions remain unanswered, such as: What form do the individual steps in the G protein signal chain take? What regulates the receptors?

One thing appears to be clear, however: the different design of the olfactory receptors in insects as compared with mammalian receptors is an indication of the fact that the two olfactory systems developed independently of each other and do not – as previously assumed – have a shared origin. “It appears that this really is a special design found only in insects,” says Wicher.

WHY ODORS MAKE FLIES GET A MOVE ON

Once the fly has smelled something with its uniquely constructed receptors, Hansson’s other colleague Markus Knaden takes over. Knaden needs none of the numerous microscopes standing around the lab. He is not interested in looking inside the fly, preferring to observe the entire animal instead. Knaden studies the behavior of the flies and thus the last link in Drosophila’s olfactory system. The questions he would like to answer are fundamentally simple ones: What does the fly do when it senses a smell or a component of a smell? Does it follow the odor trail, does it fly away or does it remain disinterested? The behavioral ecologist discovered in his initial experiments that this is not as easy to research as might be assumed with such a supposedly simple creature as a fly.

In order to find out how Drosophila’s sense of smell adapted to different living conditions in the course of evolution, Bill Hansson’s team compared several Drosophila species. However, “from an evolutionary perspective, the olfactory system of Drosophila is very conservative,” says Hansson. In reality it has hardly changed at all – except in the case of one species in which it was dramatically different. A particularly fussy fruit fly lives in the island world, in the tropical climate of the Seychelles, north of Madagascar. Drosophila sechellia loves noni fruit and noni fruit alone. The fly not only loves to eat the fruit of the Indian mulberry tree Morinda citrifolia, it also lays its eggs there. “The fruit has a very particular smell,” notes Hansson, “a mixture of pineapple and Gorgonzola.” The cheesy smell is a sign of a high acid content. It is so high in the yellow noni fruit that other flies normally die when they eat it. Not so the Seychelles variant, which is fully adapted to the exotic fruit and, indeed, highly dependent on it. “The dependency is reflected in its olfactory system,” says Hansson. Most of the neurons in the antennae are calibrated to the two odorants found in the special noni smell. They are also incredibly sensitive. The flies can sense the noni smell when only a billionth of a milligram is present in the air. Even the olfactory brain has adapted to the delicacy, which also acts as a nursery for the species: two of the glomeruli receive all of the signals from the noni neurons from the antennae. “And they are three times bigger than the corresponding glomeruli in Drosophila melanogaster,” says Hansson. While their relatives take flight when they encounter very high concentrations of the noni smell, Drosophila sechellia simply cannot resist the yellow fruit.
Such questions are usually approached using a standard experimental setup. The fly sits in a wind tunnel at the foot of a rod that it can climb up as required. A smell then floods the channel and the fly’s reaction is observed. “But only a single animal can be studied with this setup. This is very time consuming, given that we want to test a number of odor components on different individuals,” says Knaden. With this in mind, the biologist devised a setup to enable him to examine ten flies simultaneously in parallel channels.

**RESEARCH CARRIES NO GUARANTEE OF SUCCESS**

He can then introduce whichever odorant he chooses using an elaborate system. The behavior of the flies is recorded by a camera and later analyzed on the computer. On paper, and when everything was ready, it looked perfect. However: “When we put the flies in the tubes for the first time and introduced the odorants, nothing happened,” says the behavioral researcher, his frustration still obvious. Knaden and his two colleagues tried everything they could think of, but the lab animals refused to play ball.

Now he has to come up with another idea. Perhaps observing each animal individually again? Or altering the test setup in some way? He doesn’t know what he is going to do yet. The entire process from planning to the initial experiments has already cost him eighteen months. But that’s how it goes with research sometimes – there is no guarantee of success. Even Nobel laureate Adolf Butenandt and his fellow scientists had to deal with numerous setbacks before he finally succeeded in isolating the “sex-attractant substances” of the butterflies.

Was it all a waste of time, as the shocked lady said? Butenandt’s research marked a pioneering advance in the understanding of the olfactory process. And if a justification of basic research of this kind were required, it can be found here: every single bark beetle trap in use today is based on the olfactory research carried out on insects. In this instance, however, the smell in the traps does not lure the male beetles to their loved ones, but rather to their death.

**GLOSSARY**

**Dendrite**
Branching of a nerve cell, often similar to the crown of a tree. The contact points that a nerve cell receives from other nerve cells sit on the branch-like extensions.

**Axon**
The long fiber-like extension of a nerve cell that transmits electrical nerve impulses from the cell body.

**Fluorescent dye**
Dye with the capacity to absorb energy-rich light (such as UV light) and emit low-energy light.

**Patch-clamp method**
A method that makes it possible to measure how an individual ion channel can change its form and thus the current flow in the course of a few millionths of a second. The term patch refers to the small section of membrane under the pipette that also acts as a measurement diode. The membrane area is kept at a specified potential during the measurement process.

**Sensillum**
Small sensory organ in or on the cuticle of insects. It consists of sensory cells, each with a hair-like extension (cilia).
Small but mighty: In mice, around ten million olfactory sensory neurons analyze incoming air for promising odors. The corresponding figure for humans has not been identified, but it is assumed to be significantly lower.
The importance of the world of olfaction for humans, and even more so for other mammals like dogs, cats and mice, is immediately obvious to anyone who thinks about it. But the genetics and biochemistry that underlie the sense of smell are beyond most people’s imaginations. Depending on the mammalian species in question, between 300 and 1,200 genes form the basis of the ability to discriminate between the unquantifiable abundance of existing odors. These olfactory receptor genes contain the instructions for proteins that recognize the various structures of odorant molecules. Moreover – and in Mombaerts’s view this is the most significant of his many findings – they also control the navigation of axons from the olfactory sensory neurons to the brain. The entire procedure of olfactory processing takes a good 200 milliseconds. Researchers like Andreas Schäfer, who heads an Independent Junior Research Group at the Max Planck Institute for Medical Research in Heidelberg, take a stopwatch in their hands when they put mice on the trail of a smell.

But many of the questions in olfactory research remain “baffling,” Mombaerts notes. There are several reasons for this. For one thing, the secrets of olfactory processing in mammals can be decoded only by carrying out complex and time-consuming animal experiments in which the olfactory receptor genes are genetically modified in a specific way using increasingly finely-tuned methods. Faster experiments using cell cultures do not work. For another, only a small, select group of researchers have taken up this difficult scientific challenge. Peter Mombaerts estimates that there are only “around a thousand people” working on olfaction throughout the world.

A SMELL SAYS MORE THAN A THOUSAND WORDS

When we consider that Germans alone spend billions of euros every year on the pleasure of surrounding themselves with scents like vanilla, rose and musk, it may come as a surprise to learn that so few scientists are involved in researching the pathway odors take through the nose and the brain. It is also surprising in view of the fact that women, in particular, strongly affirm that their partners must “smell good” to be attractive. There is hardly anything more repellent to us than a bad smell. Biologists, physicians and psychologists are well aware of just how loaded natural smells are with information – for humans and, to an even greater extent, for other mammals. When a dog sniffs the urine of another member of its species, it can, without seeing the other animal, immediately identify its gender. When a mouse breaks out in a cold sweat, it sends out a warning to the other animals in the group. The teat secretion of a mouse guides the sucking behavior of her pups. As Peter Mombaerts stresses, there is no doubt that “olfaction is the most elementary and fleeting of all senses.” An ideal detector of body and environmental chemistry, the sense of smell is almost impossible to mislead.

Mombaerts became enamored with the science of olfaction back in 1991. At that time, a new era in olfactory research had just begun. Prior to this...
Since the breakthrough of 1991, it has gradually become clear how an odor literally rushes to the brain and is assessed, decoded, and stored there.

date, the nose was viewed as the most mysterious of the sensory organs. This was clearly due to the nature of the beast: hearing, for example, is based on a linear system of sound waves that can be detected by a biological structure with relative ease and transformed into sensory impressions. Similarly, sight is also based on the detection of wavelengths that can be understood in numerical ranges – for red, green and blue. But how can a mammal, with its limited genetic resources, discriminate between the hundreds of thousands of odorant molecules with different chemical structures? “From today’s perspective, there were some bizarre ideas floating around the scientific world back then,” remembers the Max Planck researcher, such as the theory relating to the existence of seven “primary” odors, similar to the primary colors in the visual system.

A HUGE FAMILY OF OLFACTORY RECEPTOR GENES

An article published in 1991 revolutionized the field of olfactory research. American biologists Richard Axel and Linda Buck, who have since been awarded a Nobel Prize, reported to their stunned colleagues that there are more than 1,000 genes for the detection of odors in the genome of rats. “The largest family of genes in mammals overall,” says Mombaerts. Of the approximately 30,000 genes in mice and rats, around 1,000 are involved in olfaction. This figure is lower in humans, but at 350, significant nonetheless. This genetic abundance corroborates the immense significance of olfaction. Without it, the sense of taste would be helpless – not only in mice, but also in humans. The final say on all culinary creations – be it tuna steak, hamburger, pasta, or wine – goes to the olfactory epithelium.

The family of olfactory receptor genes is remarkable in a number of respects. Unlike almost all other genes, these genes are not interrupted by so-called introns – DNA segments that do not encode information about the structure of a protein. This intronless gene structure probably made it easier for the olfactory receptor genes to proliferate with new variants in the genome over the course of evolution and to become such a huge family of genes. Moreover, in all of the mammals studied so far, the genes appear to be located seemingly haphazardly on all chromosomes. “There’s no identifiable logic here,” says Mombaerts. The team working with the scientist succeeded in demonstrating that the control areas for gene expression are “inconceivably small,” even in terms of genetic dimensions. Such control areas determine when and where a gene is activated and how its information is ultimately implemented in a protein.

Since the breakthrough in 1991, it has gradually become clear how an odor literally rushes to the brain and is assessed, decoded, and stored there. All smelly living creatures or things release volatile molecules that are almost always complex mixtures. Smells consist of hundreds of chemical components.
that waft into the nose and collide there with the olfactory epithelium. This patch of tissue is located within the olfactory mucosa and is more or less the size of a postage stamp in humans, but much larger in dogs and mice relative to their body size. The olfactory epithelium consists of three cell types: the supporting cells, which provide important assistance in olfaction, the olfactory sensory neurons, and the basal cells – adult stem cells that replace the olfactory sensory neurons and thus ensure “the strongest neurogenesis of all in the adult body,” says Mombaerts.

RECEPTORS FISH FOR ODORANT MOLECULES

Approximately ten million olfactory sensory neurons in the mouse “appraise” the incoming air; the number of neurons in humans is unknown. Around 20 fine sensory hairs, known as the cilia, protrude into the nasal mucosa. Their cell membrane houses all of the molecular components that ensure that humans can perceive several million smells, even in low concentrations, and can discriminate between thousands of them – despite having only 350 types of molecular receptors that are encoded by the olfactory receptor genes. In the olfactory epithelium of mice and dogs, around 1,200 different types of receptor proteins scan the incoming odorant molecules.

“The olfactory receptors are the basis of olfactory perception in mammals,” stresses Mombaerts. The receptor proteins, which consist of around
During their maturation, but ultimately opt for a single receptor type. Such details are important for Mombaerts, as he wants to understand how and why a cell chooses only one olfactory receptor gene for expression and – while “in biology nothing is really perfect” – why the mechanism appears to be so good. Mombaerts’s team discovered in experiments with genetically modified mice that this selection process does not involve so-called DNA rearrangements. Experts had favored this mechanism for a long time because the immune system uses it to ensure that it can recognize countless pathogens based on just a few gene segments. The Frankfurt-based researcher believes that the unusually short control elements in front of the olfactory receptor genes determine the likelihood with which a neuron chooses a particular receptor for expression.

The vomeronasal organ (VNO) looks like a tiny thread and huddles against the base of the nasal mucosa. “We demonstrated for the first time in mice that the cells of the VNO detect pheromones with their special receptors,” says Peter Mombaerts of the Max Planck Institute for Biophysics in Frankfurt. Furthermore, the VNO regulates sex and aggression in a very direct way through the perception of the pheromones of conspecifics.

The team working with the neurobiologist – who was based at The Rockefeller University in New York at that time – deleted from the mouse genome 16 genes that are important for VNO neurons, and this genetic manipulation generated defects in the processing of pheromones. Female mice barely took care of their offspring and the sexual drive of the males declined. Male mice can usually recognize, in a matter of seconds, whether a female is available to mate via pheromone messages, or whether urine originates from a strange male – something that triggers instant aggression in rodents. The approximately 300 receptors found in the VNO neurons differ clearly from the olfactory receptors in the olfactory epithelium. And, as Mombaerts’ team discovered, the axons from the VNO neurons with the same receptor do not project toward a single glomerulus in the olfactory bulb, but to 15 small glomeruli of the accessory olfactory bulb.

The scientist suspects “that the olfactory processing of pheromones takes place mainly in the accessory olfactory bulb.” The accessory olfactory bulb does not send axons to the cerebral cortex, but directly to the hypothalamus and the emotion-al centers of the brain, which control the behavior of the mice directly through secreted hormones and messenger substances.
man breathes in olfactory compounds, only the olfactory sensory neurons that express the receptors for the cognate odorant molecules are activated. Thus, dozens of receptor types are stimulated simultaneously by each odorant, but in different combinations.

“Olfactory perception is highly combinatorial,” says Peter Mombaerts. This logic is the only way humans can identify thousands of different odors with ease, while mice and dogs can potentially identify hundreds of thousands. Because small structural changes in odorant molecules alter the interaction with the receptors only gradually, the number of chemicals that can be smelled is theoretically unlimited. A receptor protein recognizes a defined part of a molecule very specifically and thus interacts only with odorants that contain this part. In higher concentrations, however, molecules with similar structures also activate the receptor.

The olfactory sensory neurons that are activated in this way transform the olfactory stimuli into electrical signals. They do this through a chain of biochemical reactions: When odorant molecules have found matching receptors on the surface of an olfactory sensory neuron and have docked there, the receptors activate, via so-called G proteins, an enzyme that produces vast quantities of the messenger substance cAMP. Positively charged ions then stream into the cell through the membrane channels that are now opened, and electrical signals, action potentials, are generated. These propagate along the nerve extension (axon) of the olfactory sensory neuron to the brain’s olfactory bulb (bulbus olfactorius) where, in the mouse, 2,000 knots made of neural extensions known as glomeruli are found.

**AN OLFAC TORY BULB WITH A SYSTEM**

This is precisely the interface at which the initially indiscriminate receptor signals become more specific. The axons of olfactory sensory neurons do not project toward the olfactory bulb in a random fashion. Instead, axons of olfactory sensory neurons with the same receptors form bundles, which are probably held together by adhesion proteins, such that “their axons ultimately coalesce into the same glomerulus of the olfactory bulb,” says Peter Mombaerts. Thus, olfactory sensory neurons with receptor A go to glomerulus A, olfactory sensory neurons with...
receptor B go to glomerulus B, and so on. The Belgian scientist gave olfactory research this fundamental insight through his pioneering experiments with genetically modified mice. When he replaced the gene for a certain receptor type with a different receptor type in the genome of the mouse, the axons of these olfactory sensory neurons did not end in their usual glomeruli. Instead, new glomeruli were formed.

**OLFACTORY PATTERNS IN THE NOSE**

The result of this process is a characteristic and complex activation pattern – a kind of glomerular map that, conversely, displays the mix of odorants an animal has smelled. A “camembert pattern” differs clearly from a “lemon pattern.” If individual chemical components are found in both smells, the patterns of the activated glomeruli overlap. Even an individual odorant molecule can evoke a complex pattern because, in most cases, several different receptors respond. The brain constantly registers which types of olfactory receptors are activated at the same time. In the example of the typical camembert pattern, the brain then generates the matching olfactory image.

Mombaerts is fascinated by the dual function of the olfactory receptors. On the one hand, they recognize odorants. On the other hand, “the receptors also guide the axons to the right place in the olfactory bulb – a wonderfully simple solution from an evolutionary perspective,” explains the olfactory researcher. At least one new glomerulus emerged in the bulb with each new gene for an olfactory receptor. Glomeruli, in turn, send their axons to the cerebral cortex where the final olfactory impression and the associated links and memories are produced.

Mombaerts and his team recently identified a second control mechanism in olfactory processing that imposes order on the cornucopia of smells at a higher level. The researchers started by showing that the olfactory mucosa can be divided into two zones with different classes of receptors. The top one, referred to as “D” for dorsal, contains olfactory sensory neurons that express class I and II receptors (class I receptors probably mainly recognize water-soluble odorant molecules). The lower zone, referred to as “V” for ventral, contains almost exclusively class II receptors. A mix of the cell bodies of the two cell classes is found in the dorsal olfactory epithelium. On the way to the brain, the axons of the class I neurons fasciculate together via a mechanism that is not dependent on the receptor that is produced. When, through genetic manipulation, the researchers forced dorsal olfactory sensory neurons that

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**SPLIT-SECOND SMELLING**

The brain wastes no time when it comes to processing odors – as Andreas Schäfer is only too well aware. The biophysicist heads an Independent Junior Research Group at the Max Planck Institute for Medical Research in Heidelberg, where he used a simple experiment to determine the “smelling speed” of mice. The animals first broke through a light barrier. At that moment, an odor was blown into their noses. The rodents quickly learned that, after sniffing the scent of bananas, they were allowed to lick some sugar water as a reward. After sniffing an apple scent, in contrast, they were left empty-handed – whereupon they retreated. “Only 230 milliseconds elapsed from the inhalation of the smell to the behavior ultimately triggered by the action,” says the researcher. “It all takes place at unimaginable speed.”

In subsequent experiments, the rodents were presented with very similar smells and, as a result, the processing time increased to 340 milliseconds – not even half a second. As part of his ongoing research, Schäfer’s team is using sophisticated techniques to switch certain groups of nerve cells in the olfactory bulb on and off to observe the resulting changes in behavior. This work is being carried out in cooperation with Thomas Kuner’s team at the University of Heidelberg. Initial findings indicate that the animals can better distinguish between smells when the neurons are rendered more excitable.
normally produce a class I receptor to instead produce a class II receptor, the axons of these neurons still aligned themselves with axons of neurons that express a class I receptor. Therefore, one of the first phases in sorting axons on their way to the olfactory bulb appears to depend only on the class of the olfactory sensory neuron. Again, as Mombaerts notes, “such a small step to unravel the odor code.”

This will have to be followed by some big steps: “We still haven’t worked out the entire logic of the system,” Mombaerts admits. Why do we perceive the molecule phenylethyl ethanol as the scent of a rose? “No idea,” says Mombaerts. Although his team has described some of the odorant molecules that bind to the olfactory receptors in recent years, the olfactory researchers still know too little about the chemical properties of many odorant molecules. “As a result, we are a long way from being able to predict how a molecule can best be altered in the test tube to create, for example, the ultimate rose scent.” Or how a scent can be produced more inexpensively and simply. The perfume industry would give almost anything for this magical code – the Holy Grail of olfactory research.

GLOSSARY

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introns</td>
<td>A non-coding section of a gene’s DNA that divides neighboring exons (the coding sections). Introns are transcribed, but then spliced out of the RNA transcript before it is exported out of the nucleus for translation into the corresponding amino acid sequence.</td>
</tr>
<tr>
<td>Olfactory epithelium</td>
<td>A tissue comprising three cell types: it is specialized in the detection of smells and is located in humans in the regio olfactoria of the nasal mucosa.</td>
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<tr>
<td>cAMP</td>
<td>Cyclic adenosine monophosphate, a biological molecule that is derived from adenosine triphosphate (ATP) and that acts as a messenger substance in cellular signal transmission.</td>
</tr>
<tr>
<td>Glomeruli</td>
<td>Spherical neural knots through which olfactory information coming from the olfactory sensory neurons is processed.</td>
</tr>
<tr>
<td>Pheromone</td>
<td>A messenger substance that serves biochemical communication between members of a species.</td>
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A Water Bath Promotes Order

If only it were always so easy to achieve neatness: Nanospheres treated with a technique developed by researchers at the Max Planck Institute for Polymer Research arrange themselves of their own accord.

The scientists produce the tiny plastic spheres in an emulsion of water and styrene, dry them, and subsequently return them to the water. Then the spheres suddenly float up to the surface, where they rearrange themselves neatly. It is not yet known why this happens. Because the spheres are very cohesive, the researchers are able to coat any object with a crystalline layer simply by submerging the object in the water and removing it again.

This technique can be used to create membranes with pores of a specific size: coatings of very small spheres can render screens non-reflecting, and a layer of slightly larger particles would repel water and dirt with the lotus effect.

(MACROMOLECULAR CHEMISTRY AND PHYSICS 2009, 210, DOI:10.1002/macp200800484)

Out of the water, into the water: Plastic spheres prepared in an emulsion and then dried (left) are resubmerged in water (center) and can then be removed from the water in an ordered layer (right).
Glassy, Not Glossy

Under very high pressure, sodium ceases to be a metal and becomes transparent.

Scientists at the Max Planck Institute for Chemistry have obtained a clearer view of the properties of metals. Working as part of an international team, they put sodium, which under normal conditions has a silvery sheen and a toffee-like consistency, under extremely high pressures.

At two million bar, which is two million times greater than the pressure of the Earth’s atmosphere, the sodium shrank to a fifth of its original size and became transparent, resembling yellowed glass. Calculations performed by the partners in this cooperative venture also indicate that it probably loses its other metallic properties as well. This would mean that it would no longer conduct a current, nor would it be malleable. It would thus no longer qualify as a metal at these high pressures. Physicists previously believed that conductivity increases as pressure rises. Now it appears that this is true only up to a certain point. (Nature, March 12, 2009)

Competition Stimulates the Breeding Process

Blue tit females feed their young more food if they previously had to compete with others for a limited number of nesting places. Furthermore, those that do find a breeding place where opportunities to nest are at a premium produce more male offspring. Some of the females that are left homeless behave like cuckoos and lay eggs in the nests of their rivals. Researchers at the Max Planck Institute for Ornithology observed these changes in breeding behavior in a long-term study during which they removed a number of nest boxes from the Wienerwald woods around Vienna, Austria. It was not possible to establish whether the competition encourages the successful females to make more effort, or whether these females are more successful per se because they naturally invest more in caring for their brood. Nor has it been fully explained how the birds influence the gender of their offspring. It might possibly be achieved with raised levels of testosterone. (Animal Behaviour, March 4, 2009)

A Stuttering Gene

It was pure chance: Some thale cress (Arabidopsis thaliana) plants placed in a growing room heated to 27 degrees Celsius failed to thrive. Searching for the cause of this failure led scientists at the Max Planck Institute for Developmental Biology to a surprising discovery. In these ailing plants, a gene required for photosynthesis was found to have a defect that also causes certain neurological diseases in humans.

The DNA of this gene contains over 400 consecutive repetitions of a three-base sequence. In healthy control plants, the same sequence, called a triplet, occurs only 20 times. This triplet stuttering means that the gene can no longer be read correctly and translated into functional proteins. What makes this observation really interesting is that similar gene defects are the cause of some serious hereditary neurodegenerative diseases in humans, such as Huntington’s Chorea, which is characterized by increasing motor dysfunction and dementia. Investigating the genes of the thale cress plant could thus shed some light on the genetic causes and development of serious hereditary diseases in humans.
Monkeys do not look at each other at all differently from the way humans do: rhesus monkeys first look members of their own species in the eye. However, by analyzing their eye movements, researchers at the Max Planck Institute for Biological Cybernetics discovered that they allow their gaze to wander aimlessly over human faces. Similarly, when humans encounter each other, their eyes meet first, whereas they scan the face of a monkey more haphazardly. This study demonstrates yet another similarity between humans and monkeys. It is not yet clear though what benefits are to be had from processing the faces of conspecifics differently from those of other species. (Current Biology, February 26, 2009)

Humans and monkeys are experts in face recognition among their own species

When looking at a member of their own species, rhesus monkeys and humans first concentrate on the eyes. In the analysis of their eye movements, red indicates a high density of looks. In contrast, when they look at another species, their gaze does not rest on a particular feature.

A network of iron atoms and organic terephthalate acid molecules on a copper substrate holds the promise of providing extremely dense data storage solutions. Made by scientists at the Max Planck Institute for Solid State Research in Stuttgart, this network might prove suitable for storing data because the spin of individual electrons in their shell makes the iron atoms behave like tiny magnets, which are normally oriented completely randomly. This is not the case in the metal-organic framework on the copper substrate, where the atomic iron magnets are all aligned horizontally, lying flat, as it were. The real point is that it is possible to exert some influence over such a flat-lying magnet. When oxygen settles on the iron atoms, the spins adopt a vertical orientation. It has been shown that this principle allows the iron atoms to flip between two states, thus enabling them to be used to store binary data. However, this currently works only when the temperature is close to absolute zero. (Nature Materials, March 2009)

Deciding direction: In a network of iron and an organic acid, the magnetic moment of an iron atom under an oxygen molecule is vertical (top). Without the oxygen on top, it lies horizontal along the plane of the network (bottom). The large image was taken with a scanning tunneling electron microscope; the sections illustrate the chemical structure (green – iron; black – carbon; white – hydrogen and red – oxygen).
Step by Step Across the Map

A new computer algorithm is solving previously unsolvable counting problems

It appears that, when seeking ways to color a map so that adjacent countries are shown in different colors, it pays not to look too far ahead: scrutinizing the map like a short-sighted person, looking at just one section at a time, will achieve this objective more quickly. Researchers from the Max Planck Institute for Dynamics and Self-Organization are solving problems of this kind much more quickly than with traditional methods, which always look at the whole problem, an entire map, for example. Physicists, mathematicians and computer scientists often look for the number of possible combinations, not only for the colors on a map, but also to describe the properties of a solid or to find the number combinations in a Sudoku puzzle. In many cases, the new algorithm is the only way to find the solution, because conventional methods often prove too slow for practical application. (New Journal of Physics, February 4, 2009)

Possible variations: A map of Germany and a Sudoku puzzle with three rows of three boxes (right) depicted as networks with different-colored nodes.

Ants Use Anti-Fungal Toxins for Protection

Leaf-cutting ants have long been doing what doctors do: they fight harmful fungi with such substances as candicines, which are also used in medicine to treat fungal infections. Scientists at the Max Planck Institute for Chemical Ecology have isolated the substances from some types of bacteria with which the ants have a symbiotic relationship. This arrangement allows the insects to protect their cultures of *Leucoagaricus gongylophorus* from a harmful fungus. The *Leucoagaricus gongylophorus* fungus is food for the ants, and they cultivate it carefully on pieces of leaf. If they were not able to rely on medical help from the bacteria, the *Escovopsis* fungus would destroy their food supplies. (PNAS, March 24, 2009)

Gardeners and their fungus supply: A leaf-cutting ant with a fragment of leaf on which the insects cultivate a fungus for food.

The Germ Cell of a Galaxy

The young universe was a very lively place: Scientists at the Max Planck Institute for Astronomy have found a positively explosive rate of star formation in a distant galaxy that can be seen from Earth at the “young” age of barely one billion years. Every year, stars with a total mass of more than 1,000 solar masses are formed there over an area measuring 5,000 light-years in diameter.

In comparison, our Milky Way, which extends over 100,000 light-years, produces on average one star of one solar mass every year. The astronomers who made this observation also solved an unanswered question about how galaxies are created. It appears that the star boom in a young galaxy starts in a small, central area and then gradually spreads out. It was previously thought possible that stars were formed throughout the galaxy at the same rate right from the beginning. (Nature, February 5, 2009)
An Automobile on the Moon …

… would be visible only through a telescope with a mirror that measured 200 meters in diameter. From Earth, it would appear only at an angle measuring some two-millionths of a degree – comparable to viewing a one-euro coin from a distance of almost 4,000 kilometers. However, this clarity has been achieved with a new measuring technique developed by an international team working under the guidance of researchers from the Max Planck Institute for Radio Astronomy in Bonn. They used the Very Large Telescope Interferometer at the European Southern Observatory with a piece of equipment that combines the beams (in the near infrared spectrum) from several individual telescopes into a very clear composite image. The astronomers chose Theta 1 Ori C as their target. This is the most massive and brightest star in the central Orion nebula to appear through conventional telescopes, such as the Hubble Space Telescope, as a single star. But the new technology allowed the researchers to demonstrate that it is, in fact, accompanied by a much dimmer star. The mass of the larger star is 38 solar masses, while that of its companion is 9 solar masses. (Astronomy & Astrophysics, now in print)

Duplicate Genes Cause Short Fingers

Our hands are one of Nature’s masterpieces, and are the tools with which we grasp the world. Their development in the embryo is already very complex. Scientists at the Charité University Hospital in Berlin and the Max Planck Institute for Molecular Genetics, also in Berlin, working with colleagues from Hamburg, Cologne, Denmark and Brazil have now uncovered another part of the complicated process that controls this development.

They found that type 2 brachydactylyia, a genetic abnormality in which the middle bone of the index finger is shortened or missing entirely, is caused by a tiny duplication of non-coding genetic sequences. Near the duplication, a regulator is found that controls a gene, BMP2 (bone morphogenetic protein 2), that is crucial for the formation of the hands and fingers. What is surprising is that the duplication is in a sequence of the genome that occurs almost identically in several different species, including chickens and mice, and has therefore hardly changed at all in the course of evolution. (American Journal of Human Genetics, April 10, 2009)
Musical Emotion Knows No Boundaries

Joy, sadness and fear can all be recognized in piano music, even if the listeners are not familiar with Western music.

The essence of music is to express emotion and to evoke emotion in the listener. But how does a person who has never heard Western music react to the unfamiliar sound? Or, to put the question another way, are humans born with the ability to understand the emotions in music, or do they acquire an ear for this through experience?

Scientists at the Max Planck Institute for Human Cognitive and Brain Sciences have now come a big step closer to answering this question, having conducted experiments with the Mafa tribe, native to the Mandara mountains in Cameroon. Although these people had never heard Western music, they clearly identified happiness, sadness and fear in piano music. They tended to perceive music with fast tempos as happy, but sadness or fear depended largely on whether the music was composed in a major or a minor key. Like listeners with a Western background, the Mafa also preferred consonance, but were slightly more tolerant of dissonance. (Current Biology, online, March 19, 2009)

Loose Blood Cells

White blood cells that are unable to penetrate infected tissue can’t fight pathogens, which is why infections escalate in patients with the rare genetic disease LAD III. The culprit is a defect in a gene identified by researchers at the Max Planck Institute of Biochemistry. It contains the blueprint for the kindlin-3 protein, which activates an anchor protein on the surface of white blood cells. The defect in the kindlin-3 gene prevents the immune cells in the blood from reaching the infected tissue. Previously, a different genetic defect had been suspected of causing LAD III. Now that the real cause has been identified, it will be possible to develop therapies. (Nature Medicine, February 22, 2009)

Money or Conscience?

Attempts to motivate consumers to buy an environmentally friendly automobile should appeal to their feelings rather than their pockets. If politicians offer financial incentives too soon, they may undermine the success of information campaigns. Researchers at the Max Planck Institute of Economics and at the Technical University in Zurich asked 1,581 potential car buyers which political measures would be effective in reducing carbon dioxide emissions. According to their findings, only a small proportion of buyers are sufficiently enlightened, but these people are opinion leaders and drive technological progress, creating a democratic basis so that the environment can also benefit from financial measures. This is because customers who make a financially motivated decision to purchase a vehicle also need a minimum of ecological awareness. Otherwise they might believe that, by paying more, they were buying the right to damage the environment. (Ecological Economics, March 2009)
Fundamental forces in space: For a few seconds, a gamma-ray burst radiates as brightly as the whole universe together, the radiation emanating to the outside via two jets. Events such as these still hide their secret: is it the explosion of an extremely massive star, a neutron star falling into the gravitational maelstrom of a black hole, or the fusion of two neutron stars or black holes?
Signals from the Beginning of the World

A star exploded just 625 million years after the Big Bang, but the radiation of this event didn’t reach Earth until last spring. This gamma-ray burst was named GRB 090423. It is the most distant astronomical object yet discovered. Jochen Greiner and his colleagues at the Max Planck Institute for Extraterrestrial Physics in Garching investigate such cosmic ‘ignition sparks’ at the edge of space and time.

TEXT HELMUT HORNUNG

It must have been a violent catastrophe. Somewhere in the early universe, a star blew up – a heavyweight with several times the mass of our Sun. In the course of this detonation, within less than ten seconds, as much energy was released as the Sun has produced during its entire 10-billion-year lifetime. The radiation signal propagated away from the site of this inferno at the speed of light. After travelling for 13 billion years, the flash finally arrived near Earth: on April 23, 2009, it flared up in the Leo constellation – astronomers observed what is known as a gamma-ray burst, GRB 090423.

The first such flash was registered more than 40 years ago. On July 2, 1967, American Vela espionage satellites detected gamma rays that could not have originated from secret above-ground nuclear weapons tests that the orbiting spies were watching for. The measurements they recorded were not published until 1973 – with the conclusion that these signals must have come from the depths of the universe.

In the years that followed, scientists investigated the gamma-ray burst phenomenon with instruments designed specifically for this purpose. From 1991 until its controlled crash nine years later, the Compton space observatory registered about 2,000 gamma-ray flashes (MaxPlanckResearch 3/2007, p. 60 ff). The scientists learned that the gamma-ray bursts are randomly distributed and arrive from all directions without recognizably predominant sites of origin in the sky.

GAMMA-RAY BURSTS – SIGNS OF AN INTERGALACTIC BATTLE?

What is happening in space? Could this be “star wars”? Is it the detonation of bombs from highly developed civilizations? The distance to the sites of the gamma-ray bursts was long the subject of great controversy. It has now become clear that the bursts come from very far away, from distances of billions of light-years. A mechanism must thus be found to explain the immense energy generation, such as conversion of mass into radiation with incredibly high efficiency. Over the years, astrophysicists have put forward at least 150 different theories – most of which have since been dismissed.

The issue is further complicated by two sub-classes that were discovered through Compton measurements: gamma-ray bursts with a short duration of less than one to two seconds, and those that typically last between ten and one hundred seconds. The short events are possibly created during the fusion of two neutron stars that had been orbiting each other for some time; alternatively, such a remnant star might have an even more compact partner – a black hole whose attractive force it cannot resist, finally plunging into its gravitational sink.

Long gamma-ray bursts constitute by far the larger population. In the presently accepted scenario, they arise when a very massive star collapses at the end of its evolution, after the fuel for nuclear fusion in its core has run out and the reactor fizzes. As radiation pressure from the inside decreases,
gravity wins and the star contracts. Finally, electrons and protons are so tightly compressed that they merge to form neutrons. This reduces the pressure in the core even further and finally the entire star collapses. Central density then reaches that of an atomic nucleus – about 100 million tons per cubic centimeter (MaxPlanckResearch 2/2008, p. 20 ff).

SCRAPS OF A STAR DISAPPEAR BEHIND THE EVENT HORIZON

Scientists still do not know exactly how arrival at this density limit transforms the implosion into an explosion. The shockwave forming at this “wall” appears to be insufficient: neutrinos – electrically neutral elementary particles that hardly interact with other particles – play a role, as does the stellar rotation, which accelerates during the collapse and channels the collapsing flow of matter into a fast-rotating disk.

Moreover, a jet traveling at almost the speed of light is ejected from the two polar regions of the collapsed star. Within this jet of plasma, shockwaves are formed by collisions of faster particles with slower ones, and these, in turn, generate gamma rays. Deeper inside, the remains of the collapsing star disappear behind the event horizon of a cosmic mass swallower: a black hole is born.

Astrophysicists are working on the theoretical details of this scenario. What causes gas to stream into a central compact object at high velocity and thus convert its surroundings into a source of high-energy light and plasma jets? If you want to understand this, there is only one thing to do: keep a close eye on nature during such a process. This is where gamma-ray bursts offer an ideal starting point, because they represent the most direct messengers of such spectacular cosmic events.

There are two practical paths of progress: Gamma rays of the burst can be measured directly in order to infer the source and the emission mechanism from its time profile and energy spectrum. Alternatively, one can observe the afterglow of the eruption in the X-ray spectrum, and also in the visible and infrared spectra.

The prompt gamma-ray burst phase is measured through the gamma-ray eyes of the Swift, Integral and Fermi satellites; the afterglow is registered at lower wavelengths by instruments including those aboard Swift, as well as

On April 23, 2009, a gamma-ray burst flared up in the Leo constellation (orange circle) – a very special event. Never before had the scientists looked so far back into the history of the universe: the light started its journey 625 million years after the Big Bang.
the GROND instrument at the Max Planck Society’s 2.2-meter telescope at La Silla in the Chilean Andes. GROND was developed entirely at the Max Planck Institute for Extraterrestrial Physics, and the detectors for one of the Fermi onboard instruments were contributed by the members of the high-energy astrophysics group at this institute.

Swift was launched into space in November 2004 and has since used its several telescopes to monitor the sky for gamma bursts. Its measurements can also detect gamma-ray burst afterglows. Scientists didn’t discover this until 1997, with the Italian BeppoSax satellite – 30 years after the incidental registration of the first burst of this type. This afterglow is believed to result from the interaction of the star’s outward-moving explosion front with surrounding matter, and can be observed for hours to days in a wide range of wavelengths, from X-ray, ultraviolet and optical radiation to radio waves.

Within one minute of detecting a new gamma-ray burst, Swift can turn its X-ray telescope to the direction determined in the sky. From measurements early in the mission, the scientists were surprised by the variations of that X-ray glow’s intensity: “Instead of the expected exponential decay, we find a much steeper decline within the first few minutes. During the first few hours, the emission often reaches a phase of constant intensity. Sometimes it then flares up again for about half an hour, during which the X-ray brightness changes by a factor of up to 100,” says Jochen Greiner from the Max Planck Institute for Extraterrestrial Physics. While the cause of the plateau phase is not known, Greiner and his colleagues take the sudden flaring as a sign of interactions within the explosion cloud.

Known as Fermi (originally GLAST for Gamma-ray Large Area Space Telescope), the most powerful gamma-ray observatory to date arrived at its observation post in its Earth orbit in July 2008. On board, the main telescope LAT

Catastrophe in the computer: Scientists now use sophisticated software to model candidate mechanisms for gamma-ray bursts. The sequence shows a so-called merger, two neutron stars that collide and merge within a few milliseconds to form a flattened disk of matter accreting onto a newly formed black hole.

LIKE RAISINS IN RISING DOUGH

Cosmological redshift is a measure of the distance of an object. Galaxies virtually swim in space-time, which expands with the expansion of the universe.

Galaxies are carried along within, just like raisins in rising dough. This motion is imposed onto any electromagnetic radiation moving through the universe: if space-time increases by a certain factor as the radiation propagates, this is reflected in a corresponding increase in the radiation wavelength, resulting in a shift toward the redder wavelength region of the spectrum.

The redshift (abbreviated z) is defined as the ratio of the observed wavelength to the wavelength of the corresponding emission process at rest in the laboratory. Astronomers use redshift to measure the distance of the object and thus the point in time when the object emitted its radiation. Accordingly, z = 1 corresponds to a distance of 5.9 billion light-years; the universe was just under half its present age of 13.7 billion years when that radiation was emitted.
Astronomers are finally observing the afterglow of a gamma-ray burst in the infrared as well. This opens up new perspectives and marks a methodological breakthrough.

(Large Area Telescope) and the GLAST Burst Monitor (GBM) with its 14 detectors share the incident gamma-ray light. LAT scans the gamma-ray spectrum at high energies of between 20 mega-electronvolts and 300 giga-electronvolts. The GBM detectors developed at the Max Planck Institute for Extraterrestrial Physics, on the other hand, monitor radiation at lower energies of between 15 kilo-electronvolts and 1 mega-electronvolt, and between 150 kilo-electronvolts and 30 mega-electronvolts, respectively, for its two different detector types. The gamma-ray monitor has an omnidirectional field of view, and raises an alarm as soon as it detects a gamma-ray burst. The satellite with its main instrument then turns to the direction estimated from the GBM data.

The detection of gamma-rays with the LAT functions differently than with an optical telescope, because light of such high energy simply cannot be deflected into a focal point. Instead, the instrument uses the pair production effect: inside the detector, the massless light particle – the photon – transforms into a pair of oppositely charged massive particles – a negatively charged electron and its positively charged antiparticle, the positron. “With the aid of a tracking detector, we use the interaction of the charged particles with the individual detector units to determine their path, from which the initial energy and direction of the gamma-ray photon can be determined,” says Gottfried Kanbach from the Garching-based high-energy astrophysics group, explaining the principle they employ to take the measurements.

GBM houses 14 crystal detectors, 12 made of sodium iodide (NaI) and 2 made of bismuth germanate (BGO). These are scintillation crystals, so named because, upon the interaction of a gamma-ray photon, they produce a brief flash of optical light – they “scintillate.” Light-sensitive photo-multiplier tubes convert this scintillation light into an electrically usable signal. The central GBM board computer processes this signal to derive an initial and still crude arrival direction. “This is then transmitted to both the LAT instrument and the ground station, from where the burst alarm is reported to a large number of observatories worldwide,” says Max Planck scientist Andreas von Kienlin. The goal is to monitor the afterglow of a gamma-ray burst in a wide range of possible wavelengths.

RISING BEYOND THE LIMITS

Only recently was it possible to open one of these wavelength windows: “We are finally observing the afterglow in the infrared region systematically as well,” says Jochen Greiner. “I feel this marks a breakthrough in method because it allows the redshift to be determined directly from the gamma-ray burst signal – instead of later measuring the redshift of the galaxy where the explosion appeared.” Moreover, it expands the accessible redshift region to earlier cosmic times. Quasars, young galaxy cores that are so bright they can be seen at great distances, no longer mark the limits.

Determing the distance is of crucial importance in the study of gamma-ray bursts. As years have gone by, it has been possible to increasingly improve the sensitivity of detectors. Until recently, however, scientists monitored the gamma-ray burst afterglow mainly in the visible spectral band. This involved first recording images of the corresponding region in the sky in order to detect the exact position of the newly appearing fireball. The redshift was not measured until the following night with the aid of a spectrograph pointed precisely in that direction.

The GROND detector developed by Jochen Greiner radically improves this situation: “The instrument combines the detection of the afterglow with a rough determination of the distance. We can now determine the distance of a gamma-ray burst within minutes, or within one to two hours at worst, to within an accuracy of about 5 percent,” says the scientist. The successful new strategy has caught on: “During the last two years, GROND has enabled us to discover as many bursts at a redshift larger than four as we had discovered in ten years before.”

GROND is an abbreviation borrowed from Tolkien’s book Lord of the Rings and stands for Gamma-Ray burst Optical and Near-infrared Detector. GROND is basically a camera that can take measurements in visible and in infrared bands. The instrument, developed and built in collaboration with the Thuringian State Observatory in Tautenburg, achieves this using six beam splitters to divide the light into seven color channels. Each channel has its own detector, so that the seven channels are exposed simultaneously.

SWALLOWED BY HYDROGEN

The distance to an object in the deep universe is determined from its cosmological redshift (see box on page 49). The so-called absorption edge of radiation from intergalactic hydrogen is an important marker. This occurs normally at a wavelength of 120 nanometers: radiation of shorter wavelengths is swallowed (absorbed) by the hydrogen atoms and the object disappears. The cosmological redshift moves this absorption edge to longer wavelengths. GROND allows this position of the shifted edge to be determined so that the recession velocity and thus the distance of the object can be derived.
The most sensitive gamma-ray observatory to date, the Fermi satellite (bottom) launched in July 2008, also carries on board an instrument called GBM. Its most important components are twelve sodium iodide and two bismuth germanate detectors. These and their power supply were built by the Astrium company under the direction of the Max Planck Institute for Extraterrestrial Physics. The digital processing unit was provided by NASA’s Marshall Space Flight Center.
GROND is essentially a camera that measures in both the visible and the infrared bands. The schematic diagram of the optics shows the entrance window at the top with the beam splitter for the visible spectrum behind it, and below, the system of lenses for the three infrared channels. GROND splits the incident light into a total of seven channels that are exposed simultaneously. The instrument was developed by Jochen Greiner of the Max Planck Institute for Extraterrestrial Physics.

Something that sounds so easy still has its technical difficulties – and this is why nowhere in the world is there another such instrument that operates in the visible and the near infrared spectra simultaneously. The infrared detectors must be cooled to a temperature of minus 210 degrees Celsius, for example. The optical detectors, on the other hand, must not be colder than minus 120 degrees Celsius, even though they are separated from the former by less than 10 centimeters. The lens system positioned in front of the infrared detectors must also be cooled to minus 200 degrees so as not to generate additional background radiation. Finally, exposures in the near infrared must typically be as short as only about 10 seconds – otherwise the detector will be dazzled by the bright, ever-present celestial background.

In order to record sources that are fainter than the normal celestial brightness in the near infrared, a telescope is usually pointed to a slightly offset area of the sky after each 10-second exposure. This is not possible with GROND, because its 45-second readout time of the optical detectors is much longer: that would entail pausing for 45 seconds every 10 seconds – an extremely inefficient observation method. “We have circumvented this problem with a small trick,” says Greiner. “Instead of moving the telescope, we internally move the image through a wobble mirror, like squinting in a circle as if we were rolling our eyes.”

GROND is one of three instruments installed at the 2.2-meter telescope owned by the Max Planck Society and the European Southern Observatory on the summit of La Silla in the Chilean Andes. GROND’s controlling computer is connected directly to the ground station of the Swift satellite. When it detects a gamma-ray burst during the Chilean night, GROND is activated without human intervention: within a short time, the current observation is interrupted, the telescope moves to the position transmitted by Swift, and a tilt mirror is placed into the beam path. Some two to five minutes after the alarm has gone off, GROND starts taking the first images. “In the case of GRB 090423, though, we had to wait 15 hours because the object had already set in the sky over La Silla,” recalls Greiner with regret.

Nevertheless, the observation of the burst of April 23 was a great success. The explosion of a high-mass star with a redshift of $z = 8$, dating it to about 13 billion years ago, is the most distant object astronomers have seen so far. With the finite speed of light, this means that, with increasing distance, they are advancing into ever earlier epochs of the universe. GRB 090423 also marks the earliest existence of a cosmic object ever observed.

THE CYCLE OF THE ELEMENTS IS INITIATED

The first generation of stars, probably born a few hundred million years after the Big Bang out of gigantic clouds of gas, were composed mainly of hydrogen. In other words, they were very deficient in metals. Only nuclear fusion reactions inside these so-called Population III stars produced the first amounts of heavier elements, such as carbon, nitrogen and oxygen, and spread them into the vastness of space when they exploded. “This gave rise to new generations of stars, and the cosmic cycle of the elements started, with its ever increasing enrichment of heavy elements,” explains Max Planck scientist Roland Diehl. Our Sun, being a relatively metal-rich star, thus belongs to one of the later stellar generations. Did the star whose gamma-ray burst was registered on April 23 belong to this very first generation of stars, or to a somewhat later generation? A fascinating question, and one that remains to be answered. Just like the fundamental question: What was the universe made of at its beginnings?
The Blue Luminescence

Two other telescope installations in which the Max Planck Society has a stake through its Institute for Nuclear Physics in Heidelberg and its Institute of Physics in Munich also have the gamma sky in their sights: H.E.S.S. and MAGIC. But neither of them measures gamma rays directly. The Earth’s atmosphere is not transparent to this extremely energy-rich light – which is fortunate for life on Earth. Instead, these instruments register what is known as Cherenkov radiation. This radiation flash is generated when a particle shower caused by incident gamma rays in the upper atmosphere propagates at a velocity exceeding the local speed of light in that medium. The initial interaction produces pairs – an electron and its antiparticle, the positron – which propagate in the atmosphere and are deflected in the electric fields of atomic nuclei. This generates secondary gamma-ray photons, which in turn produce new electron-positron pairs upon passing an atomic nucleus. A shower of high-velocity particles is thus generated in a cascade. The collective radiation from polarized atoms of the atmosphere as they experience this electromagnetic particle shower emerges as blue light – the Cherenkov radiation – for several billionths of a second at an altitude of around eight kilometers. It is precisely this blue light that is recorded by H.E.S.S. (High Energy Stereoscopic System) and MAGIC (Major Atmospheric Gamma-ray Imaging Cherenkov telescope).

Astronomical targets of the installations include the center of the Milky Way, rapidly rotating neutron stars (pulsars) and the remnants of supernovae. The two MAGIC telescopes at La Palma on the Canary Islands (photo) also specifically target gamma-ray bursts with the “stereoscopic view” of the atmosphere through their 17-meter mirrors; H.E.S.S. in South Africa is composed of four mirrors, and also targets such events when a satellite raises an alarm and the installation’s sky visibility renders it active.
Gamma-ray bursts play an important role in the study of this question, since they light up their surroundings, and matter thus leaves behind characteristic fingerprints in the form of absorption lines in the spectra. Studying the abundances of metals in this very early time of the universe also promises valuable conclusions about details of star formation under the largely unknown conditions of that time.

Jochen Greiner points out yet another aspect: “The source of a gamma-ray burst is directly related to the formation of a black hole. What type of radiation just manages to escape such an extreme gravitational field as it is building up? What are the processes that cause matter to disappear behind the event horizon of such a compact object?” Gamma-ray light is the most energetic form of electromagnetic radiation and is thus very well suited to shed light on these processes.

So what is the next move for gamma-ray burst astronomy? The previous record holder was at a redshift of 6.7. It was detected by the Swift satellite in September 2008, and the distance was initially measured by GROND to within an accuracy of 5 percent. “The relatively short time from one redshift record to the next gives us hope that further distance records will be set in the near future,” says Greiner.

**OBSERVATIONAL COSMOLOGY IS STANDING AT A CROSSROADS**

The wide-ranging importance of gamma-ray bursts for observational cosmology is now definitely being recognized. After all, looking into earlier and earlier epochs of the universe is one of its main objectives. Extensive long-term observations, such as those with the *Hubble Space Telescope*, have been conducted and hundreds of nights with the telescopes of the 8-to-10-meter class have been spent in recent years on galaxies and on the nuclei of active galaxies in order to overcome the magic limit of redshift 7, which corresponds to a universe age of 780 million years. A 2.2-meter telescope has now been sufficient to make the leap. “This means,” says Jochen Greiner, “that observational cosmology is standing at a crossroads.”

Gamma-ray bursts may show how the very first “megastars” may have formed a further 400 to 500 million years earlier, at redshifts of 25 to 30. But the warm atmosphere of the Earth sets a redshift limit of about 13 that is difficult to overcome with today’s telescopes, and corresponds to a universe age of 330 million years. To look beyond, one would need either much larger telescopes or a new generation of gamma-ray satellites. Scientists at the Max Planck Institute for Extraterrestrial Physics proposed such a mission to the European Space Agency and the German Aerospace Center back in 2007. They now hope that the current measurements of GRB 090423 will give their proposal more weight – and that the sponsors may also succumb to the fascination of the chase for cosmic records.

**GLOSSARY**

**Nuclear fusion**
Stars are nothing more than huge nuclear fusion reactors. In the centers of these globes of gas, and in their explosions (supernovae), fusion processes occur at high pressure and temperatures of several million to several billion degrees, and atomic nuclei fuse to form new nuclei. Stars such as our Sun spend most of their lives fusing hydrogen into helium.

**Black hole**
An astronomical object whose gravitational attraction is so strong that not even radiation can escape. Black holes occur in two “weight classes”: as massive as stars, and millions of times more massive. Stellar black holes are created at the end of the stellar evolution of a massive star.

**Spectrograph**
This instrument – in the simplest case a prism, used by Isaac Newton in his experiments back in the 17th century – disperses light into its different wavelengths. Dark absorption lines appear in a color spectrum, with specific lines being able to characterize the source, allowing them to be attributed to specific chemical elements.

**Stellar population**
A term introduced by Walter Baade in 1944 for stars that are similar in terms of their composition (“metallicity”), their spatial distribution and their age. A distinction is made between three populations: the first stars are called Population III, while those that formed later but relatively early in a galaxy’s evolution are said to belong to Population II, and younger stars that formed in more mature epochs of galaxy evolution – such as the Sun – are called Population I.
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Reaching **for the Sun...**

The Sunrise solar observatory has successfully completed its first balloon flight. It flew at an altitude of 37 kilometers to observe the Sun like no other telescope before. The researchers at the **Max Planck Institute for Solar System Research** in Katlenburg-Lindau are hoping for rich rewards.

**TEXT BIRGIT KRUMMHEUER**

Early in the morning, the cloud cover over the Esrange Space Center in Kiruna, northern Sweden, breaks up, just as the meteorologists had forecast. The night’s preparations have not been in vain. The white gondola containing the solar observatory is already hanging from a mobile crane as the engineers roll out the 300-meter-long empty balloon tube. The countdown has begun.

The Sunrise mission, which successfully launched on June 8, sounds like a contradiction in terms: a precise solar telescope suspended from a swaying helium balloon. Nevertheless, the scientists from the Max Planck Institute for Solar System Research, which led the project, chose the location between heaven and earth with due consideration. At its cruising altitude of 37 kilometers, the observatory has left behind more than 99 percent of the Earth’s atmosphere – and the detrimental effect it has on image definition. At the same time, the project is more cost effective than a flight into space.

A balloon flight like this is nevertheless immensely complex: researchers and engineers spent six years preparing for the project. The main mirror is one meter in diameter, making the observatory the largest solar telescope ever to have left Earth. The instruments that measure the Sun’s magnetic field and the image stabilization system are also unique – as is the mission objective: the scientists want to make the magnetic field of the Sun visible with a precision never before achieved. The researchers expect this finely woven blanket to provide them with the key to understanding many solar processes, such as how the solar corona heats up to several million degrees.

But first there has to be a successful launch. Very slowly, the balloon straightens up. Only its top portion is filled with helium. In the stratosphere, the gas bubble will expand to a volume of one million cubic meters. The moorings are released as soon as the balloon stands vertically above the mobile crane. The balloon gently lifts its three-ton load into the sky.

In the stratosphere, polar winds seize the observatory and carry it westward. At these latitudes, it doesn’t get dark in summer, so the telescope has the Sun in its sights around the clock as it makes its journey. When it landed safely in northern Canada on June 13, 1.2 terabytes of data were stored on its onboard hard disks. A lot of work – but at the same time a treasure trove for the researchers.
Final preparations for the solar observatory *Sunrise*, whose main mirror is one meter in diameter [photos 1 and 2]. Then, on June 8, things get serious: While the observatory hangs from the mobile crane, the helium balloon slowly straightens up [3]. Shortly afterwards, the balloon pulls *Sunrise* upward with a jolt [4] - the two-hour journey to the stratosphere has begun [5].
One day, a friend gave him a guitar. Since then, when he wants to relax, Andrey Rybalchenko occasionally reaches for it and strums a few bars.
Andrey Rybalchenko is a computer freak. He doesn’t spend his nights playing games, or hacking his way through cyberspace like a lunatic. Nor would one find the nerd’s hallmark stacks of empty pizza boxes in his well-lit and very tidy office. Also in many other aspects, the tall young man doesn’t quite fit the stereotypical image of the average computer nerd: he is friendly, very communicative, arranges coffee and cake for visitors, and the ping-pong paddles on his shelf tell tales of the friendly round-robin tournaments that take place in the institute basement.

Nevertheless, Andrey Rybalchenko is a computer geek – in his own way. His passion is software – that vast mass of computer code that can operate microelectronic circuits only with “on” or “off,” “0” or “1.” Software is what breathes life into them and makes them what they are: highly efficient computing devices without which almost nothing in today’s world would work – including a train trip to Saarbrücken.

But Rybalchenko doesn’t write programs for train control units, automatic teller machines or coffeemakers. His research analyzes software that already exists, or that soon will exist, for these and similar applications. “The programs are intended to carry out very specific tasks, to work efficiently, and of course, to not make any mistakes,” says the computer scientist. He develops software tools that automatically analyze and optimize the programs in these respects.

Software Errors Incur Enormous Costs

The Max Planck Society recently dedicated a separate institute in Saarbrücken to meta-research on software. Andrey Rybalchenko began working here, at the Max Planck Institute for Software Systems, two years ago. In his tenure track position, he conducts research into software verification with his own six-person working group.

Given the ubiquity of computing devices, one might think that programming was by now a pretty well run business. But the development of the computer is not only an incredible success story, but also a story of catastrophes great and small. From the dreaded Windows blue screen to the spectacular crashes of Ariane rockets and near-crashes of airplanes, to major power outages like the 2004 blackouts in the US, the consequences of software errors incur enormous costs. That is why around half of the time needed to develop software is spent on testing and debugging.

“Software is the most complex artifact that we routinely produce,” says Rybalchenko. “Anyone who thinks that their home computer is a complex monstrosity should realize that the software needed for a modern BMW or Mercedes to drive even a few feet contains more lines of computer code than Windows.” And it’s no wonder, with 200 microcontrollers managing everything from fuel injection to airbags to heated driver’s seats. All of these systems must communicate with each other, exchange data reliably and at precisely the right moment, and they must continue to function even if another component should happen to fail.

A computer is not necessarily a single machine. In distributed computing, for example, large ensembles of processors work together to carry out a single task. And of course this complex system of interactions must be well orchestrated – using software.
The computer scientist not only likes to wax philosophical about his science, he is also quick to offer the occasional quote from some of the greats: Tolstoy, Machiavelli, Bill Gates and the pioneers of computer science are just some of the words of wisdom he has on tap.

WEAKNESS FOR MATH AND PHYSICS, AND LATER FOR COMPUTERS

Why did Andrey Rybalchenko pick precisely this research field? One could say it was chance. Or destiny. “It’s like with an ant colony,” he says, referring to a passage by Tolstoy, who, in his novel War and Peace, compared Russian society with an ant colony. Which steps individuals take and why is just as unfathomable as it is ultimately irrelevant. In the end, it is the whole that counts.

The computer scientist not only likes to wax philosophical about his science, he is also quick to offer the occasional quote from some of the greats: Tolstoy, Machiavelli, Bill Gates and the pioneers of computer science are just some of the words of wisdom he has on tap, and of course also Peter the Great. This predilection for quoting great authors is a result of the classical education he enjoyed in his school-days, part of which were spent in the Soviet Union.

Andrey Rybalchenko was born in 1978 in Woronesh, an industrial city with a population of nearly one million, 500 kilometers south of Moscow. His father worked as an engineer, his mother as a bank employee. Andrey is their only child.

As long as he can remember, he has had a weakness for mathematics and physics – and at some point, also for computers, which were available at his school. “We watched the development of computers from the early days of Eastern European computing systems to the first cloned PCs to the first Pentium,” recalls the computer scientist. But he would certainly not call himself a computer kid – hardly anyone had a personal PC in those days, and games were taboo. What fascinated him even back then was the combination of math and physics tasks and programming.

Andrey attended a school that focused on mathematics and natural sciences. He participated in math and physics olympiads and took correspondence courses at a few major universities. Despite these academic pursuits, he still had time to play soccer in the street and to go skiing and play ice hockey when the roads froze over in winter. And he played guitar: “I was a big fan of blues at the time, and was determined to learn to play it myself,” says Rybalchenko. He got his chance when a friend showed up one day and gave him a guitar. He still owns a guitar, and when he wants to relax, he still occasionally reaches for it and strums a few bars.

NO INTEREST IN ALGEBRA FOR ALGEBRA’S SAKE

He has only vague recollections of the period when the political situation in the Soviet Union reached a turning point. That time was marked by economic problems and great uncertainty. Andrey Rybalchenko recalls television images of tanks in front of the White House in Moscow, and the budding
military conflicts in the newly independent republics. “It was no longer possible to sweep everything under the rug,” he says.

The fall of the iron curtain and the rise of the Internet opened up new possibilities and awakened longings for the distant realms of the West. But his family could not afford the steep tuition required for him to attend MIT or another top-ranking engineering school in the US. Nor could they afford any of the elite Russian universities in Moscow. So he had to settle for his home town for his first university experience, where he studied mechanical engineering with a focus on computer science – after all, he wanted to study something concrete: “As interesting as it was, I never wanted to explore abstract algebra or logic merely for their own sake.”

It was a chance encounter that allowed him to fulfill his desire to see the West. During Christmas break in 1997, Andrey met an old school friend on the street, who talked about his computer science studies in Saarbrücken. Not only were there no tuition fees, but there were also many opportunities to finance the cost of living through interesting student jobs. Following this conversation, Rybalchenko quickly filled out the application, and soon his ticket for Germany was booked.

Saarbrücken – that doesn’t sound like the “big wide world,” or even like MIT. A region with a known flair awaited the young Russian: ailing and defunct mines, and a metallic smell in the air. But the former Montan metropolis also has its attractions. Rybalchenko values the region’s cultural diversity, due, in part, to its proximity to France and Luxembourg. The fact that he just happened to land in a bastion of computer science – one that had even since gained some international renown – was purely coincidence. But it was a stroke of luck for the ambitious student.

Toward the end of his studies, he became acquainted with questions of software verification, and with Andreas Podelski at the Max Planck Institute for Computer Science. Podelski happened to be looking for a student for a research project in verification. Rybalchenko took the job, and Podelski later became his Ph.D. advisor. And thus the topic of his dissertation was decided. “The possibility of using scientific methods to examine programs and programming and, in turn, of using further programs to automatically analyze them, is quite fascinating,” says Andrey Rybalchenko.

But software engineering is much more complex than structural engineering. Structural engineers can determine the maximum load of their buildings relatively easily, but the limits are less clear for software. Previously, to test a program, a researcher would select a set of possible program inputs, execute the program with those inputs, and then observe the program’s behavior. But there is no
Exercise strengthens body and mind. That is why, as a matter of principle, Andrey Rybalchenko bikes to work at the Max Planck Institute for Software Systems in Saarbrücken. There, in his tenure track position, he conducts research into software verification with his own six-person working group.

Andrey Rybalchenko certainly values the conventional: “In order to understand something correctly, one must explain it to others and discuss it with them – on the whiteboard.”
guarantee that this process will identify all possible sources of errors. “And testing every possible case manually is too laborious,” says Rybalchenko.

Normally, one would use abstraction—that is, omit unimportant program details to simplify the problem. But finding the right level of abstraction is tricky. Especially for testing so-called liveness properties, this has not yet succeeded. Liveness properties guarantee that desired events occur—for example, that a certain query is executed within the program, or that a calculation terminates and doesn’t just get stuck in an endless loop. With abstraction, relevant properties can be lost, and even if they are, it’s possible that the event might in fact still occur at some point during the program cycle.

**A NEW CLASS OF HELP STATEMENTS**

Researchers have been chewing on this problem for decades. “Interesting questions about programs are undecidable!” Andrey Rybalchenko likes to quote this theorem, which acts like a driver for his work. But that just serves to increase the young scientist’s ambition. In his doctoral dissertation, he developed new analysis software for testing liveness properties. The approach is based on the theory of an entirely new class of help statements that he formulated. These so-called transition invariants can be generated automatically, and analyze the program bit by bit.

Unlike engineers, who describe continuous processes in nature and machines with the aid of mathematical equations, computer scientists use logic to analyze software, which is based on discrete yes and no statements. This quickly brings them to some very fundamental questions that also occupied the pioneers of computer science in the 1940s and 1950s, like Alan Turing and John von Neumann: What can actually be calculated with a computer, anyway? And which calculations can be carried out efficiently—that is, within an acceptable time frame? “On the one hand, this is an interesting intellectual challenge, but it is also an opportunity to make an enormous contribution to society,” says Rybalchenko.

Although his research is all about computers, his work does not rely on using computers as tools. Instead, he spends most of his time thinking in quiet solitude, assisted by paper and pencil and the scientific papers others have written. “And then there is also the whiteboard,” the Max Planck researcher stresses, and points to the many and multicolored logic equations, flowcharts and tree diagrams covering the white surface: “In order to understand something correctly, one must explain it to others and discuss it with them—on the whiteboard.”

In the end, though, the computer does prove to be a practical aid, allowing the computer scientist to directly check his ideas. “All one has to do is feed all these lines of code into the computer, then the fan kicks in because computing consumes a lot of energy, and in the end, it returns a very simple statement: O.K.—property satisfied. That is truly a great experience,” says Rybalchenko excitedly. Of course, it sounds easier than it is. And that isn’t the end of the job, either. But it doesn’t require a giant particle accelerator, nor must one wait years until the planets line up in just the right configuration.

**MEETING A PIONEER IN HIS FIELD**

Andrey Rybalchenko was able to test his own findings on liveness properties during his time at the Microsoft research labs in Cambridge, England. Following completion of his Ph.D. dissertation, he spent a few months there as a visiting scientist, developing software to verify Microsoft drivers. “The environment there is also very scientific,” says Rybalchenko. “Even back then, I was certain that I wanted to work in research.”

And that visit garnered him another very special encounter: One day, he found himself face to face with Sir Tony Hoare. “He is one of the pioneers of our field,” says Rybalchenko, recalling his “very British” manner with a grin. In the 1960s, Hoare had developed one of the first computer algorithms, and soon afterwards, had begun to think about the analysis and correctness of programs. He still works for Microsoft now, even in his retirement.

Since Hoare himself had studied at Moscow State University in the late 1950s, he and Rybalchenko even spent some time discussing their ideas in Russian. In Rybalchenko’s opinion, the fact that such casual encounters with
ones in microprocessors, the concentration of proteins in cells can be thought of as a binary system: if the concentration exceeds a threshold value, a reaction is triggered, and if it doesn’t, no reaction occurs. “Of course, this becomes interesting only when many cells interact,” says Rybalchenko.

Biologists, for example, observe thousands of cells and look to see how cancer can emerge in that ensemble if only a single cell is programmed incorrectly. The huge number of possible combinations of cell interactions results in an extremely complex system, and analyzing such a systems poses the same challenges as the verification of computer programs. “So we want to try, with our logic-based methods, to model the programming of biological cells.”

On this topic, however, Rybalchenko’s research is still in the very early stages. With verification, he has yet another success story to look back on – a research project that recently received a Best Paper Award: using a new approach that required just one input, it was possible to obtain such important information from the program sequence that the overall examination is eased significantly.

Also hanging on the wall, next to the Best Paper Award, is a group photo from a recent workshop in Turkey: computer scientists against the backdrop of the Mediterranean. The event involved more than just mental acrobatics – windsurfing, for example, is one of the many things on which the Max Planck scientist would like to spend more time. But in view of the jam-packed day-to-day life of a researcher, that, too, is akin to acrobatics: “It’s a real dilemma: do I spend the evening in the lab, or do I go to a concert or to play sports? The research
The first thing on the agenda is a better work-life balance. The holiday he finally planned is a good start.

is so interesting that it’s easy to forget everything else, and the competition isn’t sleeping.”

“CLASSICAL MUSIC – THAT ROCKS”

But Andrey Rybalchenko did manage to get his yellow and orange belt in ju-jitsu while completing his dissertation, and learn Alpine skiing in Switzerland and surfing on a reservoir lake in Saarland. And he recently scored an autograph from Russian pianist Evgeny Kissin, who gave a concert in Luxembourg. “I love classical music, too, possibly for the wrong reasons, but I think it rocks.” When there’s not enough time for such excursions, at least the ping-pong table in the basement of the institute offers a welcome change of pace. In the relaxed atmosphere there, they talk about their current work or make plans for getting together after work. Rybalchenko even recently attended a colleague’s wedding in his hometown in India. This type of relationship among colleagues is very important to Rybalchenko.

He has no plans yet to start a family of his own: “It will happen when it happens,” he says. The first thing on his agenda is a better work-life balance. The holiday he finally planned is a good start. Since windsurfing in Turkey involved swallowing quite a bit of water, he wants to learn it again properly on the sea …
Evolution after Darwin

Darwin’s pioneering work *On the Origin of Species*, in which he first formulated the principles of his theory of evolution, was published 150 years ago. This theory changed the thinking in biology significantly and influenced almost all areas of biological research. What could be more appropriate, then, than to stage a Max Planck Symposium on Evolutionary Biology in the Darwin Year 2009.

**TEXT CHRISTINA BECK**

Evolution goes on all the time.” This is the credo of Richard E. Lenski of Michigan State University. The American scientist tracks evolution in the laboratory with his team: some 21 years ago he embarked on a long-term experiment with *E. coli*. Bacteria provide good conditions for such experiments, as a bacterial population grows to billions of cells within a very short time. Studying evolution in action calls for large numbers – it’s like playing dice: if you roll the dice a hundred times, you will almost certainly get a six. Lenski hopes to overcome coincidence through the sheer volume of cells and generations alone (“Our lab has produced 45,000 generations of bacteria so far”). His ultimate aim is to identify the events that result in the advent of something new and original in evolution.

Lenski’s studies began with twelve identical populations of an *E. coli* strain. His objective was to find out whether random mutations that occurred in the past facilitate the evolution of key innovations.

**BILLIONS OF MUTATIONS**

“One of the big advantages is that you can freeze bacteria and in this way obtain fossil images,” explains the biologist. The bacteria grew on a medium with a limited supply of glucose, which also contained citrate. However, *E. coli* cannot use this citrate as a source of carbon under oxygen conditions. “In the course of 30,000 generations, not a single generation developed the ability to exploit citrates, even though each population had billions of mutations,” said Lenski.

It was only after 33,000 generations that a variant (Cit+) capable of exploiting citrate emerged – a fitness advantage that resulted in a clear increase in the size of the population. So was this an extremely rare mutation, which would explain why its arrival was so delayed? Or was it a simple mutation that had to be preceded by other mutations in order for it to be phenotypically effective? “We tested these hypotheses in experiments in which we repeated the evolution from different starting points in the population history,” explained Lenski.

Not a single Cit+ mutant occurred among the ten trillion ancestor cells in the repeat experiments, either. All 19 Cit+ mutants obtained by the scientists originated from later clones. A sequence comparison of Cit+ and Cit mutants showed that the necessary citrate transporter was generated only
when the corresponding gene was able to recruit a promoter – the start sequence that made it possible to read it in the first place. And this, in turn, had become possible only as a result of the duplication of another gene. The evolution of this phenotype was thus dependent on the population’s “genetic history.”

**HOW MICE ACQUIRE A DIFFERENT COAT COLOR**

Genetic research provides the strongest proof of evolutionary theory today. Charles Darwin could not have even guessed at such things. Indeed, the door to a more profound understanding of evolution opened only when James Watson and Francis Crick succeeded in decoding DNA in 1953. “What can genes tell us about evolutionary adaptation processes?” asked Hopi Hoekstra from Harvard University in her lecture “From Mice to Molecules.” Convergence is a fascinating phenomenon in evolution: unrelated species develop similar characteristics or a similar appearance in response to similar selection pressures. But does this phenotypic convergence imply genetic convergence? In other words: Are the same genes actually responsible for the development of similar forms and patterns? To find out, Hoekstra and her team studied coat color variants in natural mouse populations.

The mouse species *Peromyscus polionotus* populates fallow fields in the southeastern US. However, populations are also found in the bright sand dunes along the Gulf coast and more than 300 kilometers away on the Atlantic coast near Florida. They are known as beach mice and, compared to their conspecifics inland, they have lighter-colored and significantly reduced coat pigmentation on their faces, flanks and tails. The fact that the lighter-colored coat provides better camouflage in the sand dunes was demonstrated by a simple experiment in which the researchers placed a fake dark mouse coat in the dunes: it was immediately carried off and then later abandoned by a predator (probably an owl or a hawk) when it realized it had been tricked.

“At least three genes – Mc1r, Agouti and Corin – influence coat color,” reported Hoekstra. The Melanocortin-1 receptor, Mc1r for short, plays a key role here in that it controls whether the dark pigment eumelanin or the light pigment pheomelanin is produced. The researcher succeeded in demonstrating that the exchange of a single nucleotide (a T instead of a C) in
the sequence of the receptor gene in the mouse population originating from the Gulf coast altered the effectiveness of the receptor and hence changed the coat color. Arginine is now inserted in position 65 in the amino acid chain instead of cysteine, and this alters both the bonding of ligands and the potential of the receptor for signal transmission. “Such Mc1r mutations have also been observed in mammoths,” added Hoekstra.

WHY DARWIN’S FINCHES APPEAR IN EVERY TEXTBOOK

Interestingly, the lighter-colored coat in the mice from the Atlantic coast could not be explained by the same allele – the latter did not occur in them at all, nor could the researchers find any new mutations in the Mc1r gene that would have influenced the activity of the receptor. “Our findings show that a pigmentation pattern that arose convergently in different mice populations that actually developed under very similar conditions is clearly the result of completely different genetic mechanisms,” said Hoekstra. So there are different molecular solutions for attaining the same phenotype under comparable environmental conditions. The combination of different alleles of the aforementioned genes Mc1r, Agouti and Corin may well play a role here.

Using the Galapagos finches, Darwin had already clearly demonstrated the fact that patterns, colors and forms can change as a result of evolutionary adaptation processes. His drawings on this topic can still be found in every school science textbook today, and show how the finches developed a thick beak for biting seeds, a longer and sharper one for flowers, and a short, pointed beak to access tiny insects in rock crevices. As the famous naturalist wrote in his travel report of 1839: “Seeing this gradation and diversity of structure in one small, intimately related group of birds, one might really fancy that from an original paucity of birds in this archipelago, one species had been taken and modified for different ends.”

Rosemary and Peter Grant from Princeton succeeded in demonstrating the effect of natural selection directly. They studied the beaks of ground finches on the island of Daphne Major and, at the same time, recorded their food sources. In years of extreme drought, a large part of the population died and only the finches with larger beaks survived because they could crack thicker and harder seeds when the seeds they usually fed on became scarce. The beak shape is not only inherited, as the Grants discovered. It also becomes established as an adaptation far faster than had been thought. Natural selection, that apparently endlessly cumbersome and slow mechanism of evolution, can clearly create new conditions within a single generation.

In another exciting finding, the researcher couple discovered that a newly migrated larger species of bird could make better use of the thicker seeds than the long-established birds. The established residents responded to the arrival of the new competition through adaptation – in precisely the opposite direction as before, in that they now developed smaller beaks. This meant they could access food sources in rock crevices, for example, which their thick-beaked rivals could not reach. This adaptation, too, was quantifiable in one generation of the birds. The researchers call this phenomenon microevolution.

HOW GREAT TITS FOLLOW CLIMATE CHANGE

Other mechanisms also exist that could be the result of adaptation processes. Based on a long-term study carried out in the UK, Ben Sheldon from the University of Oxford demonstrated that great tits are so plastic, in other words adaptable, in their behavior that the population as a whole is successfully adapting to the rapidly emerging changes in the climate. The researchers observed the breeding be-
Behavior of the great tits in Wytham, a 375-hectare wooded area near Oxford, for five decades. No other bird population had been observed on an ongoing basis in a single location for such an extensive period.

Between 1947 and 2009, the time of egg deposition shifted forward by around 14 days. “All of the data would indicate a close link between the average time of egg deposition in the population and the temperature that prevails in the period leading up to it,” explained Sheldon. Temperatures in spring – that is, before egg deposition – have increased markedly since the mid-1970s.

Over the same period, the time window in which the majority of winter-moth grubs hatch has also moved forward. “The correlation between temperature and mating time is the same,” says Sheldon. The grubs are a key resource for the great tits, and the success of their breeding is largely dependent on the presence of these insects. Correct timing is important for breeding and the selection pressure on the timing of egg deposition is high. The synchronization between egg deposition and the peak in the hatching of the grubs is maintained through the process’s close linkage with spring temperatures. “And this would suggest that this adaptation is achieved solely through individual phenotypic plasticity,” stressed Sheldon. The British scientist also referred to “phenodynamics” in this context.

Russell D. Fernald of Stanford University proposed a bridge between genes and behavior in his lecture. Although genes do not directly specify the behavior of an organism, they code for the molecular products that develop and control brain function, and therefore make behavioral reactions possible in the first place. There are growing indications that information generated in the social context can alter gene expression in the brain, and therefore also behavior. In order to find out how social information is translated into cellular and molecular...
changes, the researchers looked for a corresponding model system. A species of cichlid from Lake Tanganyika in east Africa proved a lucky find: Fernald and his colleagues were able to use it to demonstrate the influence of social interaction on the brain.

SOCIAL CLIMBING GOES STRAIGHT TO THEIR HEADS

There are two different types of adult male cichlids: those that have a territory (T) and those with no territory (NT). Territorial males defend their territory and are extremely aggressive toward neighboring males. They scare off non-territorial males and court the females, with whom they eventually mate. In contrast, between 70 and 90 percent of NT males do not reproduce at all. Their gonads are thus small in comparison with those of the T males. They also lack the dark stripe on their heads and dots on the anal fin. These dots look like eggs to the females. In their attempts to gather them up, they collect the seminal fluid of the T male, thus ensuring fertilization.

“What is exciting about this,” said Fernald, “is that this phenotypic state can be completely reversed.” When the researchers placed NT males in a pool with smaller conspecifics, they became T males. Conversely, T males in a community with bigger territorial males became NT males. “The changes in behavior – that is, whether the animals were aggressive or not – arose within a matter of minutes,” reported the American scientist.

The changes in the brain were particularly impressive: the gonadotropin-releasing hormone controls the release of gonadotropins and thus the growth of the gonads. In T males, the GnRH-releasing neurons are eight times larger than they are in NT males. When a male was elevated from NT status to T status, the neuron size changed within a day and had reached the typical size of the GnRH-releasing neurons of T males in less than a week. The researchers also recorded an increase in the GnRH messenger RNA and the corresponding protein. Conversely, the volume of links between these neurons declined with loss of status – in other words, when a T male was transformed into an NT male. “The social behavior actually alters the brain in real time,” explained Fernald in summary.

David Haig threw light on a completely different link between genes and behavior. The researcher from Harvard University compared, first, the reproductive history of two individuals: a young woman who gave birth to her first child in her early 20s, bore additional children at intervals of two years, and eventually died at the ripe old age of 80, and the female chimpanzee Fifi from Gombe National Park, who had her first offspring at the age of 13 and gave birth to subsequent offspring at intervals of four to five years and died at the young age of 45.

EARLY WEANING OFFERS ADVANTAGES

A slide presented by Haig highlighted the central observation deduced from this: early weaning is a feature that is specific to the human lifecycle. Human children are weaned at two to three years of age, while chimpanzee young remain at their mothers’ breast for an average of five years, and even as long as seven to eight years in the case of the Orangutan. This change in the course of the evolution of human children is based on reliable access to “supplementary” nutrition. “This results in childhood in humans including an extended juvenile phase in which the offspring are weaned but still dependent on their parents for their nutrition,” said Haig. Early weaning is advantageous to the mother as she is required to invest less of her own resources (in the form of mother’s milk) in rearing the young.

Haig expects to gain a deeper insight into this mother-child relationship through the study of genomic imprinting and its effects. The following phenomenon lies behind this: two copies of each gene are found in the fertilized ovum – one originating...
from the mother and the other from the father. Imprinted genes are genes in which different effects arise depending on whether the maternal or paternal allele is read. And it may well be that there is a parental conflict at work here: the paternal genes are generally less related than the maternal genes to the fetuses arising from subsequent pregnancies – since, unlike the mother, the father is not always the same. Therefore, according to Haig’s hypothesis, the paternal genes try to mobilize more of the mother’s resources for the current fetus. The researchers thus presume that imprinting developed at the genetic loci at which either the paternal or maternal inclusive fitness is maximized through the extent of genetic expression.

MISSING GENE COPY AFFECTS APPETITE

With a view to testing these ideas, David Haig examined the genetic condition Prader-Willi Syndrome in detail. Subjects with this disorder lack the paternal copy of a gene that is imprinted, or switched off, on the maternal side, with interesting effects: in the immediate aftermath of their birth, babies with PWS have little appetite and little inclination to nurse. Within the first two years of their lives, however, they develop an insatiable appetite for food. As a result, in the course of their further development, the children become obese, while simultaneously suffering from delayed growth.

WHAT LIES BEHIND GENOMIC IMPRINTING?

This phenotype confirms the theory according to which the expression of the paternal gene should strengthen the appetite of the offspring in the phase in which they are fed exclusively on breast milk. However, the question that arises here is whether the theory can also explain the change in the appetite in the course of the further development of PWS patients. The expression of paternal genes should obviously inhibit the child’s appetite for replacement nutrition. Haig speculates as to the reasons for this: milk could be the more nutritious or immunologically more valuable nutrition. Moreover, a longer nursing phase may well delay the birth of a younger sibling. In both cases, the child that is already born benefits.

“The study of imprinted genes in humans can thus shed light on the relational interactions in our evolutionary past,” stressed Haig in conclusion.

As the famous geneticist and evolutionary biologist Theodor Dobzhansky said: “Nothing in biology makes sense except in the light of evolution.” This was impressively confirmed in the 14 lectures presented at this symposium.

GLOSSARY

Mutant
A bacterial cell in which a genetic modification has occurred.

Clone
A population of bacterial cells whose phenotype is identical.

Phenotype
The overall appearance of an organism, the sum of its characteristics.

Ligand
A substance that can bind to a target protein, such as a receptor.

Allele
Different expressions of a gene generated through minor variations in the base sequence.

Inclusive fitness
The optimization of the passing on of an organism’s own genes.

1 Hopi Hoekstra, Harvard University
2 Richard E. Lenski, Michigan State University
3 Ben Sheldon, Oxford University
4 Russel D. Fernald, Stanford University
5 David Haig, Harvard University
A lattice with lots of space for hydrogen: Metal-organic frameworks could store the fuel for fuel cell vehicles. They consist of metal compounds, shown as blue tetrahedrons, and bridges of organic molecules.
Sometimes there is a huge gap between desire and reality. The lecture theater was dead silent as Michael Hirscher presented the results of his laboratory experiments in November 2000. He had repeated these experiments for months, but the results remained the same: carbon nanotubes, until then much vaunted for hydrogen storage, were extremely reluctant to absorb hydrogen. Hirscher could only charge them with just under 2 percent by weight. More simply wasn’t possible. The publications by US researchers in respected journals had promised something completely different. They certified storage capacities of 10, sometimes even 67 percent by weight to the apparent miracle tubes – fascinating, hardly conceivable measurements. No question: the turn of the millennium was the era of the carbon nanotube. The carbon tubes were already enthusiastically feted as showing the way to the hydrogen future.

The downfall that followed was hard. And it began in November 2000 with a talk by Hirscher at a specialist meeting of the US Materials Research Society in Boston. Hirscher had gone through the experiment of his US colleagues in his own laboratory and established that the exorbitant hydrogen capacities were in no way due to the nanotubes, but were attributable in part to microscopically fine titanium fragments from an ultrasonic rod the US researchers used to prepare their tubes at the start of their experiments.

Hirscher’s talk was a hammer blow as it explained that the unbelievable storage capacities resulted not from scientific brilliance but from incredible carelessness. The consequences were dire. The US Department of Energy cancelled the funding and took its leave from hydrogen storage in carbon nanotubes. Michael Hirscher’s detective work, however, earned him the reputation of being the manager of one of the best analytical laboratories in the world.

Michael Hirscher is a physicist who researches the physics of metals at the Max Planck Institute of Metals Research in Stuttgart. Despite the sobering results, he continued with carbon for a long time. He meticulously checked what it could really do. “Today, we are convinced that carbon nanotubes really can’t store much more than 2 percent by weight. And this is clearly not enough for the hydrogen future,” says Hirscher.

The yardstick for hydrogen storage systems is the fuel cell vehicle, as this would open up the largest mass market to the energy-rich gas. The advantages are well known: in a fuel cell, hydrogen and oxygen molecules combine at a membrane to form water and thus generate electric power. The “smoke” from the exhaust is only hot steam. It doesn’t get any cleaner than that.

Vehicle manufacturers have been testing hydrogen-powered vehicles for more than ten years. The vehicles have already traveled several million kilometers, but there is still a long way to go before mass production. And one of the largest obstacles is the hydrogen storage system. Although the energy density of hydrogen is around four times higher than that of gasoline or diesel fuel, hydrogen can, as yet, be stored in the vehicle only in heavy tank systems – so it’s not really a compact solution.

The Miracle of Space in the Tank

Hydrogen could make driving a car cleaner – but there are currently no suitable storage materials for the gas. Researchers at the Max Planck Institute of Metals Research, the Max-Planck-Institut für Kohlenforschung (coal research) and the Max Planck Institute of Colloids and Interfaces are investigating the candidates for a hydrogen tank.

TEXT TIM SCHRÖDER
MOFs consist of a regular porous crystal lattice. Metal compounds, such as zinc oxide, which is added to suntan lotion as a protective pigment, are located at the corners of the lattice. The corners are connected via plastic-like molecular bridges, the linkers, which are familiar from PET beverage bottles. MOFs are very porous and surprisingly light. In the hand, they weigh as little as polystyrene granules – a 20-liter barrel can easily be lifted with one hand. Their porosity makes MOFs a promising alternative for storing hydrogen, since where there are many pores, there is also potentially a lot of space for hydrogen molecules.

The greater the number of pores or fracture edges running through a substance, the greater the surface area they offer in a minimum of space. And this is the issue for all modern storage materials, not only for MOFs: the larger the surface area, the more molecules can be adsorbed. MOFs achieve impressive values of up to 4,000 square meters per gram.

**MEASUREMENTS AS GOOD AS AN OFFICIAL SEAL**

In his laboratory in Stuttgart, Hirscher measures precisely how many molecules can be stored by an MOF. Gleaming barrels as big as wine casks filled with very low temperature liquid helium dominate the scene here. They cool the MOFs down to the operating temperature of minus 196 degrees Celsius because, as Hirscher and his colleagues discovered in a virtually endless series of measurements, hydrogen deposits in the MOFs primarily at very low temperatures.

Hirscher’s achievement is chiefly that he can measure minute amounts of MOFs that are sent to him by various research groups. A measurement in Stuttgart is tantamount to a seal of approval from a standards authority. MOFs are a relatively new class of substances that researchers became aware of only in the mid-1990s. When they discover new compounds, they can usually synthesize only a few milligrams. Hirscher often has to make do with less than a pinch of MOF for his measurements; generating reliable analytical results from this is an art. He has since worked out measurement procedures that very accurately register how many hydrogen molecules adsorb to the MOF surface at different temperatures.

The bond between the hydrogen and the MOFs is relatively weak. The molecules are not chemically bonded, but are held by physical forces, van der Waals forces, similar to blotting paper simply absorbing ink with its capillary force. This bonding to surfaces is called physisorption. Only at low temperatures and a pressure of about 20 bar is the kinetic energy of the hydrogen low enough to adsorb onto the MOF surfaces at all. MOF researchers all over the world are currently investigating what effect the pore size and different metals have on the bonding of hydrogen.

Hirscher collaborates with experts at BASF in Ludwigshafen, who can now produce kilograms of certain MOFs and who have been investigating MOFs since the mid-1990s. “MOFs have the advantage that one can create different molecules, and use a large number of metals to do this,” explains...
The 700-bar tank is state of the art technology. The aim is to beat this.

Ulrich Müller, Research Director in Catalysis Research at BASF. “We can draw on a large pool of resources to design new, higher-performance MOFs.” The best MOFs now store between 5 and 7 percent by weight of hydrogen. This is still not enough for a vehicle. At least 9 would be needed for them to be used in practice.

**TANK WITH COMPLEX FITTINGS AND ATTACHMENTS**

Nevertheless, Japan, in particular, is currently forging ahead with testing MOFs in prototypes – in its first tank systems, as the storage material is only one part of the whole story. If new types of hydrogen tanks are to be used in vehicles, the necessary fittings and attachments are also a must. And this is where all new storage concepts are still deficient. MOFs, for example, require their 196 degrees below zero. For the MOF car of the future, the hydrogen would thus first have to be cooled with liquid nitrogen when refueling. Moreover, the vehicle would require a hermetically sealed refrigeration tank, a cryotank. “The cooling consumes power and the cryotechnology would require additional space,” says Hirsch. “If the system as a whole is considered, it becomes clear that today’s MOFs do not yet perform sufficiently.”

The 700-bar tank is state of the art technology. The aim is to beat this. This would indeed be possible, in principle, as hydrogen can be packed more densely into a solid-state reservoir, such as the MOFs, than in the gaseous state. The problem is that neither the MOFs found so far nor other compounds – the complex metal hydrides, for example – fulfill this goal. Michael Felderhoff and Ferdi Schüth at the Max-Planck-Institut für Kohlenfor- schung (coal research) in Mülheim an der Ruhr are working on these storage materials.

**THE SEARCH FOR LIGHT METAL HYDRIDES**

Metal hydrides consist of light metals and hydrogen that react together when a catalyst is added. Simple metal hydrides have been around for 30 years. And they are, in fact, already being used as storage materials – on modern submarines, for example, which switch to whisper-quiet fuel-cell operation when diving.
At 2 percent by weight of hydrogen, the storage capacity of these compounds is severely limited. Around 250 kilograms of metal hydride are required to store 5 kilograms of hydrogen. In a submarine, which requires plenty of weight for the dive, the additional weight is very welcome. For vehicle manufacturers, however, which fight to save every gram of weight with aluminum bodies and magnesium sheets, the conventional metal hydrides are completely out of the question.

Felderhoff and Schüth are thus working on new complex metal hydrides in which they combine various metals. “We are trying to produce compounds of the light metals traditionally used, such as sodium and magnesium, with the so-called transition metals, such as titanium, which can bind more hydrogen,” says Ferdi Schüth, Director of the Heterogenic Catalysis Department. In this case, the weight of the molecules hardly increases, while the storage capacity for hydrogen increases significantly.

STORAGE TEST IN THE BALL MILL

The manufacturing process seems strikingly simple: the researchers use ball mills in which balls hurling to and fro pulverize small pieces of light metal hydrides together with crumbs of transition metals. When the powder is fine enough, the transition metals slowly migrate into the light metal hydrides. Even while the milling is still in progress, the researchers can detect whether the newly obtained substance actually stores hydrogen reasonably well with the aid of small durable radio sensors in the mill. If an effective metal hydride is produced and hydrogen is bonded, the hydrogen pressure in the ball mill decreases.

Michael Felderhoff has already succeeded in producing complex metal hydrides of magnesium, calcium and aluminum, which store more than 9 percent by weight of hydrogen. The problem is that these compounds release hardly any of the firmly chemically bonded hydrogen again. In contrast to physisorption, the hydrogen molecule splits into two ions when it forms the chemical bond in the metal hydride, and these two ions are virtually incorporated into the hydride.

“Our aim is thus to create less stable hydrides that bind the hydrogen less firmly,” says Felderhoff. But this is tricky, as some hydrides are then so unstable that they directly disintegrate again at room temperature and pres-
sure. So the Mühlheim-based researchers work at higher pressures. “We hope to find complex hydrides that bind sufficient hydrogen at about 300 bar.” This is something of a magical limit, because vehicle tanks for 300 bar have been available for a long time. They are considerably cheaper than the newer 700 bar models and would therefore currently be more conceivable for serial use in cars.

And the metal hydride experts have to overcome a further hurdle: when metal hydrides absorb hydrogen, the chaotically moving hydrogen molecules undergo a transition into an orderly and thus low-energy state. This releases heat, which can increase the temperature of the metal hydride so that the reaction is reversed and the hydride decomposes into metal and hydrogen.

The heat released when refueling, however, would heat the material to several hundred degrees. A vehicle fuel tank would require huge heat exchangers to dissipate the heat. Much too heavy. But Felderhoff even hopes to get a grip on the heat problem using new unstable metal hydrides – because if hydrogen atoms are more loosely bonded, less binding energy is released.

The Institute of Energy and Environmental Technology in Duisburg has designed prototypes of hydrogen storage systems with metal hydrides. In their search for the optimum hydrogen catcher, Felderhoff and Schüth also work closely with the research center for alternative propulsion at General Motors in Mainz-Kastel. “We are pleased about this collaboration – after all, the Mühlheim-based working group is the most outstanding group in the world for complex metal hydrides,” says GM Project Manager Ulrich Eberle. Eberle and his colleagues are currently pushing ahead with all three storage technologies at the same time – the 700 bar tank, the MOFs and the complex metal hydrides. The car maker is also developing its own storage materials.

**USING THE LUNGS AS A MODEL FOR REFUELLING A CAR**

“With a 700 bar tank, a hydrogen-powered car already has a range of 500 kilometers – about two to three times as far as with battery operation,” says Eberle. “Our aim, however, is to further increase the energy density of the tank with new technologies, but we can’t say with certainty right now which technology is the best.” GM has already built its first test tanks, demonstrators, with which the new materials are tested. “We want to know how well and, above all, how fast the different materials absorb hydrogen and release it again – and how often they survive such refueling cycles,” says Eberle.

For vehicle use, it is crucial that the storage system absorb and release hydrogen quickly. No one would enjoy waiting 15 minutes until the MOF or metal hydride has finally been filled. Markus Antonietti, Director at the Max Planck Institute of Colloids and Interfaces in Potsdam-Golm, believes that storage in metal hydrides and MOFs could be thwarted at this hurdle. Metal hydrides must first chemically bond the hydrogen, which takes some time. And as for the MOFs: “If you want to charge a crystal with a gas, all molecules must migrate from the outside through the pores to deep inside,” says Antonietti. This limits the speed of the gas exchange.

The chemist is thus working on porous materials that have a hierarchical construction, similar to the human lung. The gas initially permeates through large openings deep into the material, where it penetrates into increasingly finer branches, like in the bronchial tubes.
According to the researcher, this type of biomimetic, or nature-inspired, system can be charged with gas within seconds. Of course, which storage technology will finally win the race is an open question, even for Antonietti.

CARBON FRAMEWORK FROM THE SAUCEPAN

In any case, his porous carbon storage materials have the advantage of being very inexpensive and can easily be produced in large quantities. Antonietti’s raw material is straw, 20 million tons of which pile up in Germany every year. For the complex metal hydrides, on the other hand, an inexpensive metal compound must yet be found. What Antonietti does with the straw is “gourmet cooking.” For several hours, the straw must lie in water simmering at 200 degrees. Additives, such as foaming agents, ensure that the bubbles remain stable and don’t collapse again. The result is a solid, porous carbon framework. Antonietti calculated that around one hundred kilograms of porous carbon should be sufficient for one vehicle tank. And the local straw would easily be sufficient to equip the annual fleet of three million new cars in Germany.

None of the technologies is fully developed yet – neither the biomimetic carbon nor the MOFs nor the metal hydrides. But the achievements are remarkable – and the gap between desire and reality with regard to hydrogen storage is thus gradually closing.
Aboard the French research vessel the Marion Dufresne, the researchers investigated the gas emissions of phytoplankton in the southern Atlantic – usually in stormy seas and sometimes with a view of icebergs.
Searching for Traces in Heavy Seas

Precisely which gases escape from the sea into the atmosphere is important for climate change, but it is an issue that remains largely unexplored as yet. Jonathan Williams and his colleagues at the Max Planck Institute for Chemistry in Mainz embarked on board a research vessel to investigate the emissions.

A
lthough most of our planet is covered by water, it is called Earth. This could be because we know so little about the oceans and have only recently been able to investigate them. Isaac Newton’s comment, “What we know is a drop, what we don’t know is an ocean,” hits the nail on the head. One of the fields where there are large gaps in our knowledge is the exchange of gases between the ocean and the atmosphere – especially if one considers how much is known about comparable processes on land. This knowledge is sorely lacking, because the fact that seawater can absorb or release gases plays a major role in global atmospheric chemistry. It is precisely to enable us to take these processes and their effects on climate change better into consideration that we must investigate them in greater detail.

We have particularly little knowledge about the group of organic – that is, carbon-containing – compounds that are volatile, meaning they evaporate quickly. Experts call these volatile organic compounds, or VOCs. They are chiefly released into the air by trees and plants, and the plants in the ocean are called phytoplankton. These substances can have an important effect on key compounds in the atmosphere, such as ozone. For many of the VOCs, very little research has been done as yet on what role the oceans play.

WHAT SUBSTANCES DO MARINE PLANTS RELEASE?

On a global annual basis, plants on land convert about 56 billion tons of carbon, present in the atmosphere as carbon dioxide, into biomass. This plant matter weighs roughly 100 times more than the total world population.

Although the mass of the plants in the oceans measures just one hundredth of that of the plants on land – because there are no trees, for example – they absorb about the same amount of carbon: 49 billion tons. For the most part, researchers can only guess what other substances are exchanged and in what quantities. There is thus an urgent need to investigate the interface between the ocean and the atmosphere in order to understand the global atmospheric chemistry of the past, present and future.

To enable the unanswered questions concerning the atmosphere-ocean interface to be addressed, the European Union provided a budget of two million euros for the period 2005 through 2008 for a research project called OOMPH – “Organics over the Ocean Modifying Particles in both Hemispheres.” The OOMPH project brought together an international consortium of nine research groups from Germany, France, Greece, the United Kingdom, Italy, Belgium and Hungary, and was conceived and coordinated by my group at the Max Planck Institute for Chemistry in Mainz.

Our project investigated organic compounds – from their production by phytoplankton in seawater to the transfer into the gas and aerosol phases and onward to regions of the upper atmosphere. An essential part of the work involved a bit of an adventure: a journey through the Roaring Forties aboard the French research vessel the Marion Dufresne. This part of the southern Atlantic, between 40 and 50 degrees south latitude, owes its name to the roaring winds that often sweep across it at hurricane force. The voyage was to take us...
Sea in green: The green streaks of the algal bloom are clearly visible on an aerial photograph.

Sea in blue: Outside of the plankton bloom, only the sky determines the color of the ocean – plenty of opportunity for the scientists to measure clean air as a reference.
from South Africa to Tierra del Fuego in Chile and lead us through a particularly lush bloom of phytoplankton.

**PLANKTON GASES IN A LAB TEST**

But before we installed our measuring instruments on board the ship, the OOMPH team worked in the lab to determine which particular organic emissions actually originate from phytoplankton and how they depend on light and temperature. We wanted to determine in advance which organic components we were likely to encounter during the ship-based measurement campaign.

The team thus selected several types of phytoplankton that are plentiful all over the world and grew them as monocultures in incubation chambers. Clean air was streamed through the culture chambers under different day/night light cycles and this flushed all of the gases emitted by the phytoplankton out of the chamber and toward the detectors. Interestingly, all of the phytoplankton cultures we measured emitted carbon monoxide, albeit in varying quantities. The plants clearly changed their carbon monoxide emissions as a function of the incident light. We thus knew that phytoplankton release carbon monoxide from the ocean into the atmosphere during the daylight phases.

Even after the lab tests were completed, it was still not time to put to sea. We first wanted to draw up a forecast as to which volatile organic compound emissions we could expect to record during our measurement campaign on the ocean. To this end, our team combined the VOC emission data of different phytoplankton species with new satellite images of the global phytoplankton distribution.

By combining the emission rates and the emission distribution in a global model, we were able to estimate the global emission of selected compounds from seawater. In this way, we proved that the annual quantity of isoprene that escapes from the ocean is between 0.31 and 1.9 million tons, and thus well below the 500 million tons that the plants on land emit.

These results made a valuable contribution to the heated debate over a 2006 publication on satellite measurements. That study championed the view that marine isoprene from a phytoplankton bloom in the southern Atlantic had influenced the properties of the clouds above it. The OOMPH team’s findings lead us to take the view that too little isoprene rises from the sea to influence cloud formation. It is our opinion that a different explanation will have to be found for the changes observed.

**TRIAL RUN OFF THE WEST COAST OF AFRICA**

We were now finally able to start the preparations for our ship-based measurement campaign, which was intended to show whether our results from the laboratory and from our model could be confirmed in nature. But before the actual measurement campaign in the southern Atlantic, we set out on a trial run to test how the newly developed instruments worked. The journey took us through the calm waters of the tropical Atlantic off the west coast of Africa.

The analysis of the tests showed that the ideal region for the efficient measurement of sea emissions had to fulfill the following three criteria: it should be free of terrestrial influences from its environment, and it should have high wind speeds and a high phytoplankton occurrence that must be easy to locate. The Roaring Forties in the southern summer thus offer the ideal conditions.
Our measurement campaign aboard the *Marion Dufresne* took place between January and March 2007 and took us from Cape Town, South Africa to Puntas Arenas, Chile and back to Durban, South Africa. At this time of year, a large region of phytoplankton bloom that looks like a huge flower when viewed from satellites forms in the southern Atlantic.

**RESEARCHING ON SHAKY GROUND**

There is hardly a better region on Earth to look for absolutely clean air than the southern Atlantic Ocean – far removed from dry land and human activities. The strong winds are also welcome, because they promote the exchange of trace gases between ocean and atmosphere. However, these winds often develop into hurricane-force storms, which provided all of us with a range of new work experiences. It wasn’t only the fact that we had to carefully tie down all of our instruments. Every movement on the rolling ship becomes a balancing act. And, at least in the beginning, some of us were very pale around the gills as we monitored our measurements. It wasn’t the results that caused us to blanch, but the seasickness, which affected almost every one of us for a couple of days during the voyage.

Every now and again huge waves towered up in front of us, and our ship rocked so much that one or another of us was sometimes thrown off their chair. Under such conditions, the captain naturally forbade us to venture out on deck, or even to the mast in the bow where we had installed the inlets for our analytical instruments.

Whether we were eating, walking across the deck or playing basketball in the ship’s hold, when the ups and downs of the ship often made us feel as if we were flying or falling into an abyss – our daily routine became very shaky. Despite the difficult working conditions and one or two technical difficulties that we simply had to improvise our way through, we busily collected data.

Before we came to the region of the algal bloom, the measurements proved how clean the air above this part of the ocean is. The team detected extremely low terrestrial emissions, such as nitrogen monoxide and nitrogen dioxide, during the voyage. The measurements of the unpolluted air provided the background for the research on the plankton bloom. As we reached this region, we could see from the deck that the water suddenly turned green. At the same time, the measured levels of many components suddenly showed extreme peaks.

As expected from the lab tests, increased carbon monoxide values could also be measured in the seawater in the bloom region. As we reached this region, we could see from the deck that the water suddenly turned green. At the same time, the measured levels of many components suddenly showed extreme peaks.

**ENCOUNTER WITH A FISHING FLEET**

Interestingly, the composition of the VOCs changed as the ship crossed the bloom. The same was true of aerosols. Electron microscope images of aerosols from this region showed gelatinous fibrous lumps on sea salt particles with significantly more organic matter than is found outside the bloom. In the aerosols, we detected methane sulfonic acid, a product of DMS oxidation. The changes to the gas and aerosol composition correlate with the varying phytoplankton distribution we observed on our voyage.

Although we planned our route through one of the most remote and inhospitable regions of the world, we did not escape the effect of human activity – this seems to be almost impossible on the Earth of the 21st century. Just as we were crossing a high-chlorophyll region on February 2, 2007, the *Marion Dufresne* completely unexpectedly encountered a large fishing fleet consisting of around 150 to 200 ships at about 45 degrees south and 59.3 degrees west. The fleet caught squid, mainly at night, and used a huge number of very powerful lights to lure them to the boats. This illuminated fleet is so bright that it can easily be seen on...
satellite photos. The light requires around 200 megawatts of power – as much as a small power station – which the fleet produces with its diesel engines. In a region that is characterized by the natural emissions of phytoplankton bloom, the ships thus represented a powerful source of anthropogenic gases, especially nitrogen monoxide and nitrogen dioxide.

OZONE FROM SHIP EMISSIONS AND PLANKTON GASES

Although the objective of the OOMPH ship-based campaign was to investigate natural emissions, this chance meeting provided us with a further interesting finding: with an atmospheric chemistry model adapted to ocean measurements, we demonstrated that a large amount of ozone is produced where the emissions from ships and the natural emissions of phytoplankton bloom coincide. This is a problem that should not be underestimated, because fishing normally takes place in regions that are rich in phytoplankton, where fish find a plentiful supply of food. Our future atmospheric chemistry models must thus take into account how the emissions from the phytoplankton and the ships interact.

At the end of six or so weeks of taking measurements aboard the Marion Dufresne – a little less than three weeks for the outward voyage and somewhat longer for the return – we had collected a great deal of valuable data. Together with the tests done in the lab, the modeling and the satellite measurements, they reveal much about the volatile organic substances that escape from the sea. The pioneering work done in the OOMPH project has thus successfully characterized many processes that affect organic compounds. This more than compensates for the often inhospitable conditions on board, as do the encounters with whales and icebergs that gave this research expedition its very special appeal.

GLOSSARY

**Phytoplankton**
Encompasses the types of plankton that carry out photosynthesis. It is the first link in the aquatic food chain.

**VOC**
Volatile Organic Compound; the volatile organic compounds include methane from marshes, rice cultivation and cattle farming, as well as traces of solvents and combustion residues from engines, plus isoprene and terpenes released by plants.

**Aerosols**
Droplets or solid particles that are suspended in the air and play an important role in chemical processes in the atmosphere, as well as in cloud formation.
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Mothers-in-Law on the Doorstep

What sounds like an adventure is actually hard work: In order to form a clear picture of the Kyrgyz people uncluttered by romantic notions, Nathan Light collected the life stories of around 300 real men and women. As a scientist at the Max Planck Institute for Social Anthropology in Halle/Saale, his interest centers on the changes in family relationships in the country’s post-communist society.

TEXT BIRGIT FENZEL

For outsiders, Kyrgyzstan lies on the old Silk Road in the heart of Central Asia, bounded by China, Tajikistan, Uzbekistan and Kazakhstan. This description conjures up images of endless caravans slowly winding their way from Asia to Europe. Laden with valuable goods and precious knowledge, their routes skirt places where the early religious and political history of Eurasia took shape. Notions of warlike nomads and armies that used advanced technology to conquer the surrounding regions and unite them under their dominion have captured people’s imaginations.

“Such images aren’t wrong, but they distort our view of the far more complex whole,” says Nathan Light of the Max Planck Institute for Social Anthropology. What passes for knowledge tends to be an amalgam of clichés pieced together from travel brochures and vague retellings of the more dramatic moments in the history of Central Asia. “Everyone’s heard of Genghis Khan, but only very few Europeans are interested in the realities of daily life, either in his day or the present,” continues Light, who first began his fieldwork in Central Asia in 1989.

Curiosity is mostly limited to either the exotic or the extreme – the same preoccupations that prevailed when ethnological interest in Europe first emerged in the early 16th century. Part of the fascination with exploring the unknown regions of Europe lay in weaving tales of the human and natural curiosities to be found in these newly discovered lands. Gradually, over time, ethnology has moved on from this approach. “My task is to move beyond such preoccupations and study the minutiae of daily life: how people are born and how they grow up, start a family and lead a normal life. These days, we are interested in much more than just exotic differences,” says Light.

With this in mind, a number of researchers from the Max Planck Institute are conducting fieldwork in different parts of Kyrgyzstan. Projects range from the country’s religious, legal and political practices and its history to the working lives of the rural population and the daily routines of the apartment block dwellers in the metropolis of Bishkek.

STUDYING FAMILY AFFAIRS IN THE FIELD

Like many of his colleagues in the “Socialist and Postsocialist Eurasia” department headed by Director Chris Hann, Nathan Light has a particular interest in regions where the balance of power is shifting and society is in upheaval. It is at pivotal moments like these that ethnologists can find some exciting structures revealed to them. In fact, US-born Light’s current project is headed in just this direction. Describing his primary interest, he explains: “I want to study the changes in family relationships in post-communist society.”

His research work balances British social anthropology’s focus on investigating concrete social relationships, and American cultural anthropology’s
The bride and groom with their families after their civil wedding ceremony in Bishkek. This photo, like the majority in this article, is taken from the book by Judith Beyer and Roman Knee entitled *Kirgistan: A Photoethnography of Talas* (Munich, Hirmer Verlag, 2007)
more abstract culture and practices that center on meanings and discourse. “In the modern world, people have come to think of distinct bounded social units as each having its own unique culture and history. Everyone is taught to join a collective identity with a shared history and culture, and some kind of national or local territory,” Light explains.

In order to form a picture of the Kyrgyz people uncluttered by the romantic notions conveyed by tourist brochures, Nathan Light collected the life stories of around 300 men and women. Over the past four years, he has spent a total of 18 months in the country. Starting out from the capital city of Bishkek, he has traveled to the villages of Talas Province, as well as in the southern and eastern parts of Kyrgyzstan, including the Tianshan (“Mountains of Heaven”) around Lake Issyk Kul.

At first he attempted to strategically select his fieldwork destinations, but once on-site, he discovered that planning did not provide the expected outcomes. “I tried to choose villages that I considered to be typical, but in the end, it became obvious that every one of them has its own history and cultural peculiarities.” Finally, he settled on five villages and the city, Bishkek, for data to make his comparisons. In his interviews, his interests as an ethnologist led him to query the life histories of his subjects in general, and their familial relationships and interpersonal conventions in particular.

Despite being a stranger asking about personal family matters, he encountered few reservations: “In most cases, people took pride in being interviewed, and enjoyed the idea that someone was interested in their life story.” Especially older people were aware of their role as witnesses of times past and present: “Most of them regarded the story of their life as a personal account of the complexity of historic change.”

NO ONE MISSES MUD FLOORS AND STRAW BEDS

They told Nathan Light and his tape recorder just how they managed in the days of communism, and of the new living conditions that a market economy and liberalism have brought them. Describing his impressions, the Max Plank researcher explained that “society there has changed enormously since the demise of socialism. Partly in terms of greater economic opportunities and freedoms, but also with regard to the greater willingness of the Kyrgyz people to accept a return to traditional forms of familial relationships, religion and social organization.”

This newfound liberty also allows people to take a more differentiated view of the world and things in general: “As a rule, it is evident that the Kyrgyz are able to exercise much greater awareness in living their social options than in the past.”

But even during the socialist era, family relationships were an established part of soviet politics. Most Kyrgyz originally lived as nomadic herdsmen grouped together in clans. In the 1920s and 1930s, however, they were forced to abandon this lifestyle and take up agriculture, working on state-owned farms as collectives along with other ethnic groups. That was when the Kyrgyz learned to grow their own wheat, potatoes, tobacco and other things that they had previously been able to obtain only by bartering for Russian or Volga-German produce.

In the interviews, many of them showed little sign of regret for the passing of their old way of life. “They also tell of the dirt-floored houses that they lived in, sleeping on piles of straw. Rather than speak of the violence of collectivization, most Kyrgyz I have talked to prefer to describe their earlier practices as somewhat backward, and emphasize the benefits of improved housing and agricultural technologies,” says Light.

There were other aspects of Kyrgyz life that were also massively affected by the Soviet regime. In preparation for an entirely atheist society, all religious and spiritual practices were strictly controlled by the authorities. Family gatherings from weddings to funerals were required to conform to Soviet ideology, which forbade traditional practices such as arranged marriages and the payment of a bride price. Sons and daughters were to be entitled to equal treatment and have the right to choose their partner of their own free will. The prohibition of the old wedding traditions also put an end to the material transactions that, in the past, were customary when two families were joined in this way.

From this perspective, the restrictions cut right to the heart of Kyrgyz society. After all, family ties, the transfer of goods and social relationships are among the most important elements in life for these people – not to mention the accompanying festivities that are
celebrated at great expense. “The principal events also include birthdays, circumcisions, housewarmings and the handover of a dowry,” says Light, listing other notable highlights in Kyrgyz life.

To celebrate all of these events in a fitting manner, Kyrgyz custom demands the attendance of dozens, if not hundreds, of guests drawn from the extended family of the father, as well as friends and members of the new family to be joined in marriage. Countless gifts are presented. “The process often takes hours,” as Light knows from experience. The gifts are not exclusively for the host, but may also be intended for his relatives – garments for the grandparents, for example, or material contributions to the celebration itself.

A MASTER OF CEREMONIES KEEPS THE GUESTS IN CHECK

It is the responsibility of the tamada, the master of ceremonies, to ensure that the celebration proceeds as it should. He notes who takes center stage at any given time and decides which games should be played or what else should be done to prevent boredom from setting in among the guests. The figure of the master of ceremonies also appears to the ethnologist to be an indicator of cultural change. “In post-Soviet Kyrgyzstan, the tamada has become one of the most prestigious professional groups,” says Light. Everyone can name three or four famous masters of ceremonies. Depending on how far they have to travel, they can pocket up to 400 euros for each appearance. “The tamada with whom I spent the most time was also responsible for making sure that the guests behaved properly,” adds Light, recalling his experiences of Kyrgyz weddings.

The master of ceremonies is thus also concerned with keeping the guests’ alcohol consumption within bounds. “He might, for example, hold competitions that require the players to bring as many unopened bottles of vodka as possible up on stage from their tables – that in itself is interesting, because the original tamada in Georgia is responsible for keeping the wine flowing at such festivities.”

During the Soviet era, these celebrations were on a much smaller scale and more domestic. The principle, however, was the same: wedding celebrations meant a close bond between the participating families – a bond forged for life, not just between the bride and groom but between the two family lineages. “According to the Kyrgyz way of thinking, your child’s parents-in-law are the people you can depend on most,” Light says, explaining the special relationship between the parents of the bride and groom.

But such significant and costly events must be preceded by careful selection: marry in haste, repent at leisure. Marriages in Kyrgyzstan are among the most important methods with which to create strong social bonds between two groups. But allowing the parents to decide who will marry whom can also lead to complex problems, as our scientist discovered during his research: “Especially if, for example, the couple has already made their own – different – choice.”

THE RIGHT TO A FREE CHOICE OF PARTNER

In pre-Soviet times, some couples resolved the conflict with their parents by taking flight. If the couple could manage to spend time together against the will of their parents, the latter would ultimately give their consent. Also, it would be hard to marry the young woman off to some other man, since she had already been together with another.

With arranged marriages banned under Soviet rule, many young Kyrgyz exercised their right to a free choice of partner. Another wedding ritual also became widespread: ala kachuu – the abduction of the bride, in which the potential groom, supported by his friends, seizes the young woman and carries her off to his parent’s home. There she finds her future mother-in-law and the other women of the family waiting for her. They try to persuade the girl to stay by telling her that she will be treated well, and by telling her that only picky girls would reject this new family. They play on the girl’s desire to avoid insulting her potential in-laws, and they also rely on the belief...
in the force of elder women’s curses. Other popular ways to exert pressure include placing loaves of bread on the threshold. Sometimes the mother-in-law herself will lie down at the doorstep – respect for the staples of life and the honor due to age mean that stepping over either would lead to misfortune.

A RUNAWAY BRIDE BRINGS SHAME

Once the victim has spent the night in the house where she was taken after being kidnapped, she is generally considered to be no longer a virgin. This puts a lot of pressure on her to leave quickly or not at all. By running away, she would bring shame on her family, and the mother will often tell the girl to stay. “Even today, the authority of the parents is very strong,” says Light. “If the mother of the abducted girl says she should stay, she will not run away.”

Even in pre-Soviet times, women were abducted for marriage – for example, if the bride price was too high or the cost of the wedding celebration was beyond the parents’ means, or because social differences prevented the union from taking place. But generally there was an understanding between the young woman and her abductors who, through this act, were able to circumvent social constraints.

This is more easily understood against the background of the complex roles allotted to the two sexes in this culture. For most unmarried women, the subject of relationships with men was, and still is, a rather difficult one: their parents may be all too keen to see them married off, and they themselves might like to marry soon – yet they may not, under any circumstances, let it show. Public opinion interprets an overly conspicuous interest in a forthcoming marriage as a lack of modesty and self-control. Many women have saved themselves from this dilemma by staging a kidnapping. A timely abduction prior to the wedding has also enabled more than one young woman to avoid a marriage arranged by her parents. This was at least one way for a girl to make her own choice. “But there have also been cases in which young men have used abduction as a means to compel their own parents to accept their choice of bride,” adds Nathan Light.

In his interviews inquiring into people’s life stories, our researcher also discovered that, in the early years of Soviet domination, arranged marriages were still widespread despite the ban – though the matter was treated with much discretion. “If the girl did not agree, her parents would permit their daughter to be abducted by the young man’s family,” says Light, describing a common practice at the time. Of his interviewees, a 65-year-old woman, told him how she was escorted on foot by two sisters-in-law of the young man to the house of her future parents-in-law; another woman described how she was carried away on a donkey cart.

For an ethnologist, these Kyrgyz versions of bridal abductions offer fascinating insights into the structures of social behavior: “Four or five different groups of actors are following an identical cultural convention here.” The entire procedure begins with the abduction of the young woman by a young man aided by his friends. Then the boy’s older male relatives must go to the house of the bride to apologize to her parents and deliver gifts. Next, the sisters-in-law of the bride are permitted to go to her – and may either help to secure her release or persuade her not to flee.
“Each of these actions is replete with cultural conventions that dictate how the participants may achieve what they set out to do. The whole process is governed by strict rules of correct conduct,” says the Max Planck scientist. Without knowledge of the local social background, the procedure is hard to understand: “From an outside perspective, it is impossible to understand how this practice could, over time, become an entirely normal nuptial strategy.” It has been banned, it is arduous and dangerous – but it is also accepted. “And ultimately it overcomes some of the problems associated with other marriage traditions.”

The issue has since been taken up by some international human rights organizations and national women’s rights groups, but in Kyrgyzstan, their criticisms of violent bridal abductions are often not understood. “Many Kyrgyz do not see the woman as being abducted against her will,” says Nathan Light, summarizing the many opinions he has frequently heard expressed by the inhabitants of the towns and villages between Bishkek and Talas. The general obstacle to change is that many rural Kyrgyz consider abduction of a bride to be perfectly natural – interesting to talk about because full of surprising outcomes, but a normal way to find a bride for the household. “For them, that is the way things are.”

WHAT REALLY MATTERS IN THE END

In his 300 interviews and the many hours he has spent participating in and observing the most varied day-to-day events and festivities, Nathan Light has, however, noticed signs of change. “There are many efforts being made to combat bridal abductions, and some of them are very successful.” This is a multi-layered phenomenon that seemingly has complex roots in society. The concept of a romantic love match with free choice of a partner may be accepted by broad sections of the Kyrgyz population. In fact, for more than a few, it is a romantic ideal. But there are so many obstacles to the implementation of this concept in practice that many see abduction as the better alternative. And ultimately, time is an important factor, as the Kyrgyz would prefer to build their relationships over an extended period of time and develop strong bonds. “And in a good relationship, a difficult start is easily forgotten,” says Light.
Wind energy is a technology with a future – and with origins that can be traced far back into the past. One of its pioneers was Albert Betz, who was a Director at the Max Planck Institute for Fluid Dynamics in Göttingen from 1947 to 1956.
the wind tunnel. Betz also carried out wind tunnel research together with another prominent engineer, Ludwig Bölkow, who was working for Messerschmitt. These trials demonstrated that the flat sails propagated by the Dane Poul La Cour in 1890 as the ideal solution were in fact no match for streamlined profiles. Once the rear section of such sails was streamlined, the performance almost doubled. This was because turbulence ceased, air resistance fell and lift increased. By 1940, sails of this shape had been successfully fitted to 130 mills in place of the originals.

These and other improvements came at a time when a public electricity grid was just being developed, and wind energy technology was in danger of being sidelined. The successes achieved in theory and in practice were all the more important in that they laid the foundations in physics and technology on which the refinement of wind energy systems would later be based.

The Second World War brought development to an abrupt halt: during the War, plans for new windmills were abandoned the world over, and the few installations that were under construction were not completed. When the War was over, wind energy projects remained on the back burner – oil was plentiful and cheap. It was not until the oil crisis of 1973 that numerous industrialized countries began to seek ways to reduce their dependence on oil. Here, at last, wind energy offered one possible alternative.

ENERGY FROM ALTERNATIVE SOURCES – THANKS TO THE OIL CRISIS

In parts of Europe, America and Asia, windmills were the principal sources of energy until well into the 19th century. They were never quite forgotten, but it took the oil crisis to revive interest in wind energy. The governments of a number of industrialized countries encouraged the development of wind energy converters (wind-powered turbines for electricity generation). This would soon bear fruit, for example in the US, where wind energy converters with a capacity of up to several hundred kilowatts were grouped together in wind farms. Some mega-installations were also built, with output running into thousands of kilowatts.

Such projects were undertaken in Germany, too: in 1982 the 100-meter tall Growian (Grosse Windanlage, or Large Converter) with a design capacity of up to three megawatts was built at the mouth of the River Elbe. Growian, however, didn’t measure up to the stress and strain. Cracks soon appeared, as winds are stronger by half at a height of one hundred meters than they are at ground level, where their speed is slowed by a variety of obstacles. That, and the fact that the wind aloft is more constant, is why wind turbines are always erected on tall masts.

The design of such wind power installations generally follows a basic pattern: the rotor is shaped like a propeller and is combined with a gearbox and generator to form a single module. The module sits on top of a tubular or lattice mast and is turned into the wind with a fixed rudder. Windmills like this are a competitive option wherever there is plenty of wind and few other energy sources available. However, using the windmill to produce electricity can be problematic: when demand is high – in the evenings, for example, when the wind drops – the windmill is unable to supply enough energy. Conversely, when the wind is strong, there is insufficient use for the power.

Albert Betz died on April 16, 1968 in Göttingen. Three years prior to this, he was awarded the Carl Friedrich Gauß Medal in honor of, among other things, his meritorious achievements in formulating the basic principles of aerofoil theory. Betz did not live to see the boom in wind energy in Germany. In 1976, the author Felix von König came to the following conclusion in his book “Windenergie in praktischer Nutzung” (Wind energy in practical use): If, apart from water power, wind energy should one day be the only source available, wind power would certainly be inadequate to guarantee a regular power supply in today’s sense, since the wind is too irregular. However, for a pre-industrial standard of living it should suffice – thanks to wind energy and our knowledge of physics and technology, there will be no return to the Stone Age. Albert Betz surely would not have disagreed.

Albert Betz in 1930 standing beside a three-component balance. The object being measured is a rectangular wing.
The Max Planck Society attaches great importance to a family-friendly human resources policy. Just how strongly the Society values the right balance between operating targets and employees’ personal interests is reflected in the certificate it received for the second time from the non-profit company beruf und familie, an initiative of the Hertie Foundation. Federal Minister for Family Affairs Ursula von der Leyen and Parliamentary State Secretary Dagmar Wöhrl from the Federal Ministry of Economics presented certificates to the Max Planck Society and numerous other enterprises at a ceremony in Berlin in mid-June.

“Our employees are fundamental to our scientific success – the men and women whose commitment and achievements make us what we are today and in the future.” For MPS Secretary General Dr. Barbara Bludau, this can be realized only if the human resources policy takes the needs and wishes of those who work for the MPS into account. This explains why the MPS made the decision some years ago to be audited by beruf und familie. The first certificate was awarded in 2006. The second certificate is valid from 2009 until 2012. In its latest audit, beruf und familie looked at how successful the Max Planck Society has been thus far in putting family-friendly measures into practice, and specified which new areas should be given priority in the years to come. The independent auditors helped management personnel at the Max Planck Institutes review their progress and select new directions to be addressed. In the future, management personnel will be arranging meetings on a more family-friendly basis, making provisions for part-time employment even in scientific posts, and appointing representatives to advise on issues of family compatibility. They will also investigate whether a separate budget is required.

With a wide range of opportunities for employees to pursue personal and professional development and better balance work and family interests, for example through the provision of local childcare facilities or the option to use the pme-Family Service, as well as flexible rules on working hours, the Max Planck Society is already preparing for the future and taking account of demographic change. The MPS will also continue to report annually to beruf und familie on the new goals it sets and the measures taken to achieve them. The MPS is entitled to use the certification logo – which enjoys Europe-wide protection – on publications, brochures and job advertisements for the next three years. The same applies to the 80 Max Planck Institutes – the MPS is the only scientific organization in Germany to be certified in its entirety.

At the presentation ceremony in Berlin, Federal Minister for Family Affairs Ursula von der Leyen welcomed the growing interest on the part of businesses in a more family-friendly human resources policy. Despite the continuing economic crisis, more companies than ever qualified this year: certificates were presented to a total of 322 employers. "Productivity and employee motivation are 17 percent higher at family-friendly companies than elsewhere, while absenteeism is 13 percent lower," added Dagmar Wöhrl, Parliamentary State Secretary at the Federal Ministry of Economics, referring to a survey carried out on behalf of beruf und familie.
In recent years, the Max Planck Society, represented by the Max Planck Digital Library, concluded agreements with five publishing houses and covers the cost of open access publications out of central funds. The publishers include BioMedCentral, Copernicus Publications, the Californian Public Library of Science and Springer, via its “Springer Open Choice” program. An agreement has also been reached with Britain’s Institute of Physics and the German Physical Society (DPG) regarding the important New Journal of Physics. The agreements cover all articles whose corresponding authors specify a Max Planck address.

This form of open access is frequently referred to as the “gold road,” and it now makes it easier for Max Planck scientists to have their first submissions published in the relevant journals. These publications are accessible free of charge worldwide via the Internet. In this case, the publishers derive their income, not from subscriptions, but in the form of a publication fee paid by the authors or their institutions.

The Max Planck Digital Library (MPDL) and its predecessors have been investigating the possibilities of funding various open access business models since 2003. The five contracts will initially run for a trial period. The publishing houses selected are scientific publishing companies that offer innovative open access business models and are willing to adapt their publication and billing workflows to the needs of a scientific organization as complex as the Max Planck Society. Both the MPS and the publishers are venturing into new territory in signing these central contracts. The challenges facing both sides are, on the one hand, to guarantee a speedy and uncomplicated publication service for scientists, and, on the other, to develop an accurate and transparent billing structure.

The central contracts including acceptance of costs take some of the pressure off the material budgets available to individual scientists or research groups at the MPS. However, the gold road to open access is viable only as long as it is not misused by publishing houses as an additional source of income. In other words, the total costs paid by the MPS to any given publisher for individual open access articles, plus subscriptions to journals or magazines, must not increase. These costs are already high, and for some time now, the prices for subscriptions in particular have been rising far faster than the average rate of inflation.

In the course of this year, the experience gained during the pilot phase will be compiled in a project report. They will also be submitted to both national and international bodies. For example, as part of the EU “Study on Open Access Publishing” project, the MPDL is currently taking the lead in classifying and evaluating the various open access business models available on the market.
A record 56 participants attended the 13th Annual Conference of Equal Opportunities Commissioners, highlighting the women’s demand for knowledge. In line with the redrafted equal opportunities provisions, all of them took on their positions just this year – marking the first time that all were elected at the same time MPS-wide.

A lot of work lies ahead for the new equal opportunities commissioners, much of which is based on 18 pages of provisions to promote equal opportunities. The equal opportunities commissioners are involved in “all personnel, organizational and social measures relating to sexual equality, the reconciliation of family life and work, and protection against sexual harassment in the workplace.” “Past achievements in equal opportunities policy are certainly important milestones for the Max Planck Society,” was the assessment of Peter Gruss, Max Planck President, of the MPS’s commitment to date in a letter sent to the MPIs on the new central works council agreement. However, the president said that the MPS would have to “redouble its efforts,” as Germany could not afford the hemorrhaging of its intellectual resources from a socio-political perspective.

Marlis Mirbach, the MPS’s central equal opportunities commissioner and, once again, conference organizer, firmly believes that there is sometimes a wide gulf between what is required and what is achieved. She is, however, pleased that all but five MPIs succeeded in carrying out the election of the equal opportunities commissioners as provided for by the central works council agreement. The fact that not all of the institutes adhered to the defined timeframe of between September 1 and December 1 is a pardonable transgression. It is the task of the independent equal opportunities commissioners to enforce the rights provided by the new body...
of provisions. Marlis Mirbach was pleased to offer her support at the meeting at the MPI for Developmental Biology. Even the title “equal opportunities commissioner” requires explanation. Mirbach explained: “we are aiming to gain greater acceptance from men, who can consult the equal opportunities commissioner on issues concerning the reconciliation of family life and work.” The fact that only women can be elected to this office by women is due to the provisions of the Federal Equal Opportunities Act, which has been in force since 2001. In 2003, federal and state governments also agreed to apply its key elements in the jointly funded research institutions.

All in all, the promotion of equal opportunities is seen as an important tool for staff development, and as an interdisciplinary task for which all employees are responsible, but especially management and employees with managerial responsibilities. Mirbach told the conference participants: “A key part of your job is to help achieve this through mediation,” referring them to the first point on a to-do list. The MPS’s principles of equal opportunity state that “specific objectives” should be developed at the institutes. These objectives may relate to staff or to social or organizational issues, but most importantly, the equal opportunities commissioner should be involved. Mirbach said that the achievement or, if applicable, reasons for non-achievement of these objectives would be evaluated quarterly and reported to the Federal Ministry of Education and Research.

As in the past, equal opportunities commissioners will be involved in recruitment. However, this will now also apply to the appointment and induction of scientists. To carry out this task, the equal opportunity commissioners had to elect one scientist for each individual section – no easy undertaking, as most of the equal opportunities commissioners are non-scientific staff. The equal opportunities commissioners identified candidates and cast their votes by mail prior to the conference. The votes were counted in Tübingen. Elisabeth Binder will serve as the new section equal opportunities commissioner for the Biology and Medicine Section (deputies: Josefa Oehm, Cristina Afonso), and Elena Lieven for the Human Sciences Section (deputies: Ute Dercks, Gundara Wößner). Marlis Mirbach is anxious to see how their involvement in the complex appointment procedure works out. She said: “The fact that the commissioners will deliver an opinion for the Senate, which ultimately decides on appointments, could well give rise to conflict.”

Ingrid Gabel-Becker, who as central equal opportunities commissioner also attends the meetings of the appointment committees, then told the conference how the Fraunhofer-Gesellschaft manages this issue. And the conference was taken aback by the self-assured presentation of Anke Geßner, equal opportunities commissioner at the Social Science Research Center Berlin and spokesperson for all equal opportunities commissioners at the Leibniz Association. She even appears directly next to the executive board in the organizational chart. The sociologist is calling for comprehensive participation in salary grade promotions, the debate about performance-based pay and assessment criteria. She summed up by saying: “Equality means quality. It is not some kind of optional altruism, but a key factor in science policy.”

### MIT Doctoral Students Visit IMPRS in Stuttgart

Hans-Georg Libuda was delighted to hear that his hard work had paid off. As coordinator of the International Max Planck Research School for Advanced Materials, it had taken him countless transatlantic e-mails and telephone calls to set up a Winter School with the Department of Materials Science and Engineering at the Massachusetts Institute of Technology (MIT) – high praise from Boston came as a welcome ‘thank you.’

The idea for the meeting came right from the top: around two years ago on a trip to the US, Max Planck President Peter Gruss had met with the president of MIT. Even before he returned, IMPRS-AM management was asked to investigate the possibilities of cooperating in the training of Ph.D. students. Finally in late March, during spring break, 5 professors and 20 doctoral students and post-docs visited Stuttgart.

A series of presentations and a poster session were held under the heading “Nanoscale Materials: Structure, Properties, Relations” to explore the interfaces between the research done by the visitors from MIT and that of the two Stuttgart MPIs for Solid State and Metals Research, as well as the adjacent university.

For the two IMPRS spokespeople and Directors Bernhard Keimer and Eric Mittemeijer, an important aspect of the workshop was to recruit American doctoral students to spend time at the IMPRS as post-docs. The chance to make personal contacts should also make it easier for German Ph.D. students to visit MIT after obtaining their doctorates. The American academics were impressed by the range of subjects covered by the now more than 50 IMPRS run by the MPS. They regretted that there were no employees at the MIT faculties whose job descriptions paralleled that of an IMPRS coordinator, whose task includes reviewing applications from doctoral students, organizing workshops and developing long-term partnerships and projects.
Noble Support for the Florida Institute

The Max Planck Society has recruited no fewer than three Nobel Prize winners to provide support for the Florida Institute in the US: Bert Sakmann will become Scientific Director, while Henry Kissinger and Günter Blobel will join the Board of Trustees.

Bert Sakmann, long-time Director at the MPI for Medical Research in Heidelberg and winner of the 1991 Nobel Prize for Medicine, will launch the research program at the Max Planck Florida Institute as Scientific Director. He is currently still working as an emeritus professor at the Max Planck Institute for Neurobiology in Martinsried, near Munich. Max Planck President Peter Gruss is confident that Sakmann is an excellent choice, thanks both to his international scientific reputation and his extensive experience with the Max Planck Society. “He absolutely personifies our mission and our standards of excellence. He will be an ideal ambassador for the Max Planck Society while the Institute is establishing itself in Florida,” said President Gruss.

Sakmann intends to initiate a program of research in Florida that will clarify the precise structure of the nervous system in the cerebral cortex of mice. This part of the brain is responsible for memory, attention, speech and consciousness. Aided by his team, Sakmann plans to develop a three-dimensional atlas of nerve cells, dendrites and axons. The first step will be to label the various cell types with special fluorescent markers in order to visualize and quantify the distribution of neurons.

In addition to this, Henry Kissinger agreed to join the Institute’s Board of Trustees. He, too, is a Nobel laureate: after serving as a long-time security advisor and Secretary of State under Presidents Nixon and Ford, he was awarded the Nobel Peace Prize in 1973. It was former German Chancellor Helmut Schmidt who introduced Henry Kissinger to the Max Planck Society. However, the link with Henry Kissinger dates back even further: in the late 1970s, there was talk of appointing him as successor to Carl Friedrich von Weizsäcker at the Max Planck Institute for the Study of Living Conditions in the Scientific and Technical World in Starnberg.

Biochemist and Nobel Prize winner Günter Blobel, a German native who now works in New York, is also a member of the Board of Trustees. Blobel is best known in Germany for his commitment to the reconstruction of the Frauenkirche in Dresden.

Code of Ethics Revised

The new “Rules of Good Scientific Practice” at the Max Planck Society entered into force on March 20. They were drawn up by the Ethics Council, chaired by international law expert Rüdiger Wolfrum, acknowledged by the Scientific Council and adopted by the Senate. The sections on scientific publications, in particular, from the previous code of November 2000 were amended and extended. New sections were incorporated covering data protection, possible conflicts of interest between science and industry, and measures to protect whistleblowers, or those who denounce wrongdoing or falsification. The Administrative Headquarters (research law department) will print the new rules in the form of a brochure. These will be sent to the Max Planck Institutes and facilities and will be issued to all new staff upon appointment. The first version of the code was adopted at the end of 2000 as a response to a similar document produced by the German Research Foundation (DFG), which was drawn up following some serious cases of fraud in the German science system. The DFG now grants funding only to universities and research institutions that have established rules of good scientific practice.
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