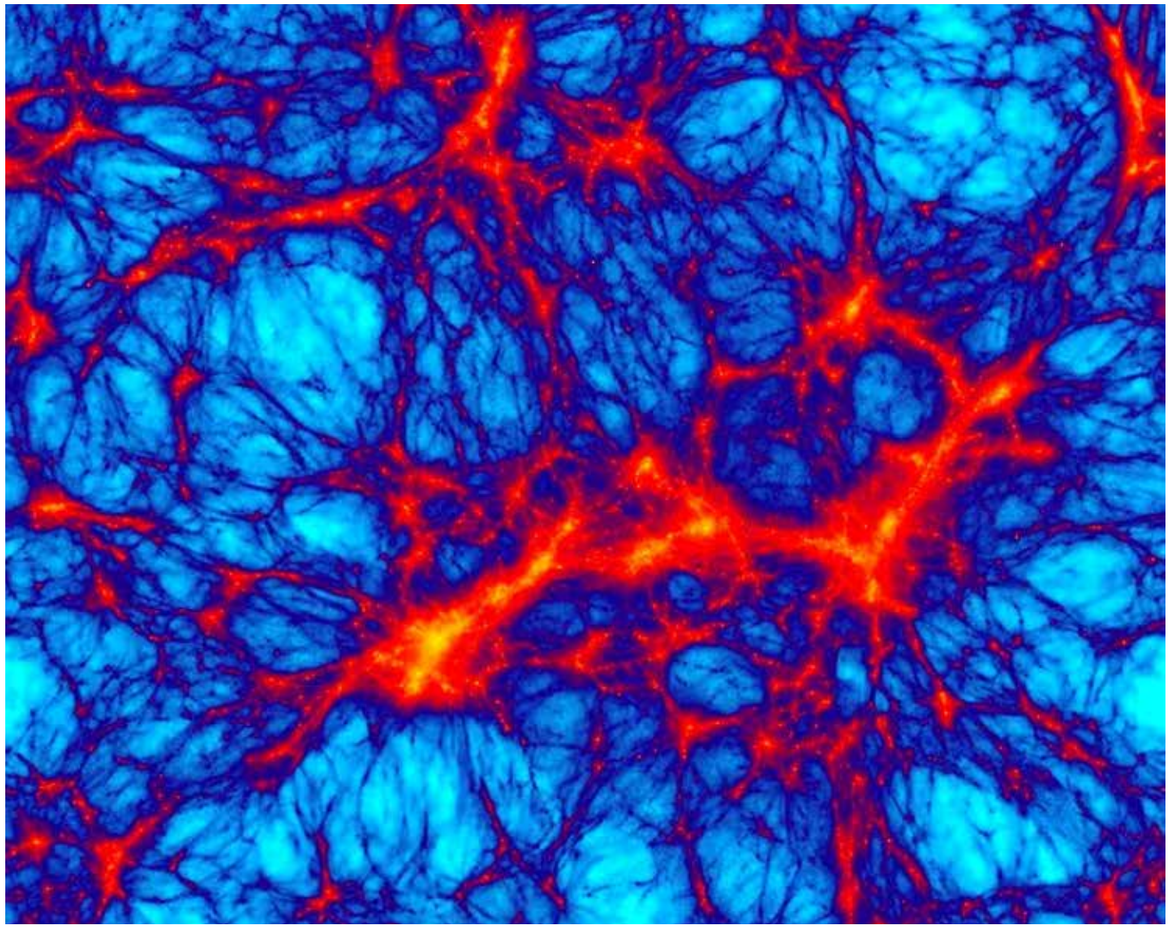
german
research
Magazine of the Deutsche Forschungsgemeinschaft

3/2012



Universe: Intergalactic Winds | **Change of Presidency:** Interview with Matthias Kleiner | **Volcano Chemistry:** Reading Gas Emissions like Hieroglyphs | **Catholic Processions:** A Very Public Ritual | **Brain Research:** The Power of Music | **Decision-making Processes:** Gotcha | **Innovative Medical Technology:** Faster, More Precise and Visible

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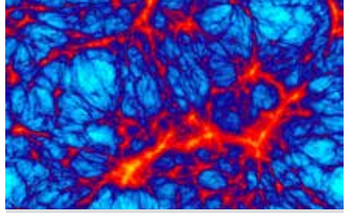
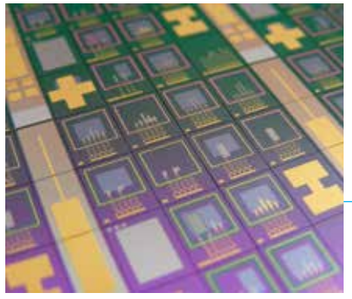


Cover: Craig Booth/U Leiden
A digital look into the universe: A network of cosmological filaments (red) in a computer simulation. The small nodes contain individual galaxies, the larger ones up to several hundred.



"In the hearts and minds of the research community"

From the Excellence Initiative to gender equality standards, from research and scholarship to politics, from Germany to the wide world: Matthias Kleiner served as President of the DFG for six years. Before leaving office, he spoke to us about what has been achieved and what has not, about changes in intense times and plans for the future – and good wishes.

Illustration: DFG / Ausserhofer

german research: Mr. Kleiner, how does it feel to be on the cusp of leaving this office and the office of President of the DFG?
Matthias Kleiner: Filling the role of DFG President is a tremendous privilege, and I leave it with a glad heart and a feeling of deep gratitude. You know at the outset that your time in office is limited …
… to two periods of three years …
… exactly, and it's a good rule, although two periods of four years might also be a possibility worth considering since it takes a good year to learn the ropes. But it's also a very intense time, demanding and fulfilling both physically and mentally. So it's a good time for it to come to an end.

Do you leave with a feeling of satisfaction?
I don't know if satisfaction is the right word. Recently I looked at my first DFG New Year reception speech from 2007, which was very programmatic. I stressed how the funding portfolio and funding activities should be more focussed on actual research practice and the needs of researchers. I was already using words such as flexibility, modularisation, and a better start for early career researchers. And, in fact, we have achieved a lot of these things. We have also achieved a lot through the research-oriented standards on gender equality, which were met with more acceptance by DFG member organisations than perhaps anticipated. I am satisfied with that, as I am with the Excellence Initiative, with which the scientific and political communities have done a lot of good in the German research system and raised its international profile. I am also pleased with our activities at international level and the expansion of European and global research collaborations.
Where do you think the DFG, and you yourself as President, should have done more?
We could perhaps have done more in relation to open access, not so much in terms of our own activities but in wider political terms. A second point is the question of how the DFG supports academic careers beyond professorships. This is an area where we could perhaps have done more in terms of actual project funding.

Clearing Out

It was mid-December and Matthias Kleiner's second to the last day in office when he gave this interview to "german research" in Bonn, following his formal farewell at the DFG's Head Office. The departing President was clearing out his office – as could be seen by the boxes outside the door and the partially cleared desk. He had previously explained that he did not have any prepared comments for this issue of "german research", and agreed instead to an interview to look back over his time in office – a special approach for a special occasion.

During your six years in office you often said that science carries society. Is this true, and is it any different from when you first took office?
Yes, it has become even more evident that the future of our society is closely linked to the future of science and research. This has been recognised by society and in particular the government in that investments in research have continuously and significantly increased. We also see it in the way that the government has been willing to seek and follow advice from the scientific community. The Excellence Initiative was entirely science-driven. And although it is investing more money in research, the government has resisted the temptation to increase its influence. Indeed, I would say that there is now even more respect for the independence of the scientific community, or at least of the DFG.

An ideal situation, it would seem – will it stay that way?
That remains to be seen, especially if the situation regarding public finances changes further. I would encourage all those with decision-making responsibility to have the same courage they showed in mid-2009, when, at the height of the first financial crisis, no less than 18 billion euros were awarded in additional research funding. But the financial aspect is only one factor. The other – the qualitative question, if you like – is whether we can maintain the same independence and protect basic research funding against expectations of short-term utility. We must be aware of this and be prepared to take appropriate steps if necessary.

Being aware and taking steps – that might have been the motto for the last phase of your time in office. We witnessed a paradoxical situation in which the president of the organisation which, more than any other, promotes competition in research, was warning against the consequences of competition.
Yes, but not without reason. Competition is one of the most important driving forces in research. But in many cases this has resulted in excessive competitive pressure which is nowhere more evident than in the third-party funding provided to researchers through the DFG. The importance of this funding has grown and basic funding for universities has continued to shrink. This has caused widespread unease, which we as a self-governing organisation are particularly aware of, and indeed we have also come under criticism ourselves. But it's also our job to make politicians and the general public aware of this unease. So it's only logical for the DFG President to say that we need much better basic funding for the universities, which are and must remain the core of the research system, we need more research without third-party funding, and we need a phase of productive leisure.

Competition in research and research funding has become increasingly fierce. What role does the DFG play in this competition, and should the DFG – and you yourself as President – have defended this role and its achievements more robustly?
To start with your last question, no, I don't believe so. The reason – and this answers the first question too – is that this is precisely what makes the DFG what it is. It's an organisation that thinks prudently and acts intelligently. It has a clear focus, but keeps sight of the whole spectrum of interests. It has the power to achieve integration – within the research system, between the research community and government, and between the federal and state levels. And it has the lowest self-interest of any stakeholder.

Six years is a long time for a person to serve in office. How does a job like this change a person – how have you changed personally during this time?
It certainly makes you more experienced and composed and enables you to approach difficult situations with more confidence and assurance. You can do this because you have a supportive and empowering environment. In the DFG, this means the Head Office and the statutory bodies. Obviously, the President is the most visible representative of the organisation. And as President you can initiate things and get things moving. But you can also become more impatient, and I'm sure that applied to me on more than one occasion. But you can achieve little on your own, and you have to make sure that the people you need and the people who matter are motivated and involved. And in saying that I acknowledge that together we've achieved an enormous amount.

You will soon be leaving this environment. You kept quiet about your future plans for a long time and it was only at the last minute that you announced your intention to return to your professor's post at TU Dortmund University …

Yes, because it seemed the most natural choice and I'd be surprised if anyone thought it an unusual decision. First and foremost I'm a university lecturer and researcher, and that's how one is elected to a post like that of DFG President. You remain a professor, both during your time in office and afterwards. I could also hardly imagine taking up another similar post on 1 January – I would need a break first. So I've made the conscious decision to return to my university, taking with me the many new ideas and insights I've gained during my presidency. I am also keen to become more involved in the academies again. And finally, I will have a range of responsibilities both old and new to keep me busy. In February 2013, for example, I will become a member of the Scientific Council of the European Research Council.

At your formal farewell to the DFG's Joint Committee, you said humorously that you would be observing what the Deutsche Forschungsgemeinschaft does from the exalted position of a former President. What should it be doing, and what should your successor Peter Strohschneider be doing?
Well, I don't want to give any advice even in this DFG magazine, neither to the DFG nor to my good friend Peter Strohschneider.

But you certainly wish them both well.
I wish Peter Strohschneider the same excellent support that I received and success in achieving the difficult balance between securing research funding and maintaining a self-governing organisation. As for the DFG, I hope that it continues to enjoy independence and success for many years to come. I also wish it a less stressful period. But above all I hope that it retains its place in the hearts and minds of the research community and that researchers continue to value it for what it is: their DFG.

Interview by Marco Finetti and Dr. Rembert Unterstell.

"A successful advocate and ambassador"

Farewell ceremony for DFG President in Berlin

The DFG bid farewell to Matthias Kleiner at a ceremony held at the Humboldt Carré in Berlin (pictured below). At the event, which was attended by 200 guests, prominent representatives of the scientific community and politics paid tribute to Kleiner as a successful advocate and ambassador for German research at home and abroad and a socially engaged researcher.

DFG Secretary General Dorothee Dzwonnek began by underlining the nature and character of the DFG as a self-governing organisation for German research and "a reliable partner to those who want to carry out high-level research in Germany" – describing the framework for Kleiner's presidency.

Speaking on behalf of the universities – the DFG's core members and the heart of the research system – Prof. Horst Hippler, the President of the German Rectors' Conference (HRK), outlined the numerous research policy initiatives and funding developments that have taken place in the DFG during Kleiner's time in office, to which he gave his personal support and drive: from improved

funding opportunities for young researchers and pioneering high-risk research to the "Quality over Quantity" initiative designed to stem the flood of publications and the DFG's research-focussed equality standards. Through the implementation of the Excellence Initiative and his campaigning for its continuation and expansion, Kleiner has earned lasting recognition with regard to the German university and research system, Hippler stated.

Federal Minister for Education and Research Annette Schavan (in centre picture with the outgoing president and DFG Secretary General Dorothee Dzwonnek) paid tribute to Kleiner's achievements as an ambassador for Germany as

a location for research and innovation. With his consistent commitment at European and international level, she said, Kleiner not only increased Germany's standing in research and research policy, but also raised the profile of research and research policy in Germany. In conclusion, the minister thanked Kleiner for the "amiable manner" with which he fulfilled his role.

The Minister of Science for Lower Saxony, Johanna Wanka, also emphasised Kleiner's commitment to the internationalisation of the German research landscape, as well as his "sensitivity to the issues faced by universities". Schavan and Wanka also applauded Kleiner's social engagement, making special mention of his work as Chairman of the Ethics Commission on Energy Transition. "Matthias Kleiner is a researcher who cares deeply about the community," said Schavan.

Speaking on behalf of the European and international research organisations, as well as personally, Pär Omling, the President of the European Science Foundation, praised Kleiner's commitment to the expansion of the European research landscape.

The future DFG President Peter Strohschneider (pictured right with Kleiner) underlined Kleiner's "understanding of the interests of science in general" and thanked him for the "friendliness, friendship and fairness" with which he performed his role and paved the way for his successor.

Kleiner responded to these tributes with personal thanks of his own: to his wife and three children, members of the political sphere, the academic and scientific communities, research organisations, and, not least, the DFG and the researchers who work for and with the DFG as applicants, reviewers and committee members, and finally the staff at the DFG Head Office and Secretary

Illustrations: DFG / Ausserhofer

General Dorothee Dzwonnek. "The office of DFG President is the best the research world has to offer," he said by way of conclusion. "It is an enormous privilege to have served in this role."

Nicole Bobrowski

Reading Gas Emissions like Hieroglyphs

Volcano research: Scientists who investigate what is going on inside our planet often work very close to active volcanic craters and use complex techniques. Recent international measuring campaigns have revealed that some information can also be obtained with simpler instruments and from a relatively great distance to the volcanic sites.

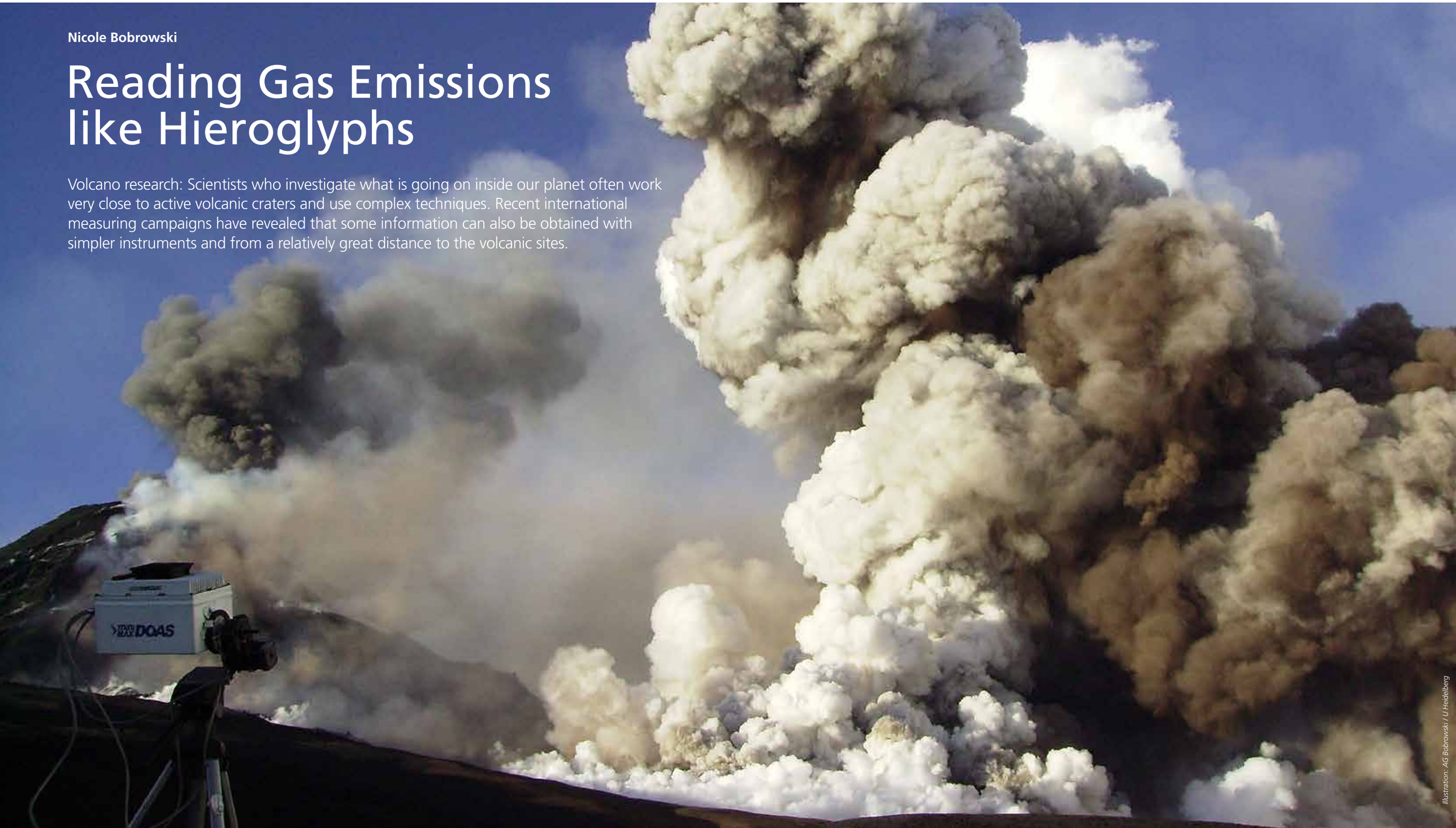


Illustration: AG Bobrowski / U Heidelberg

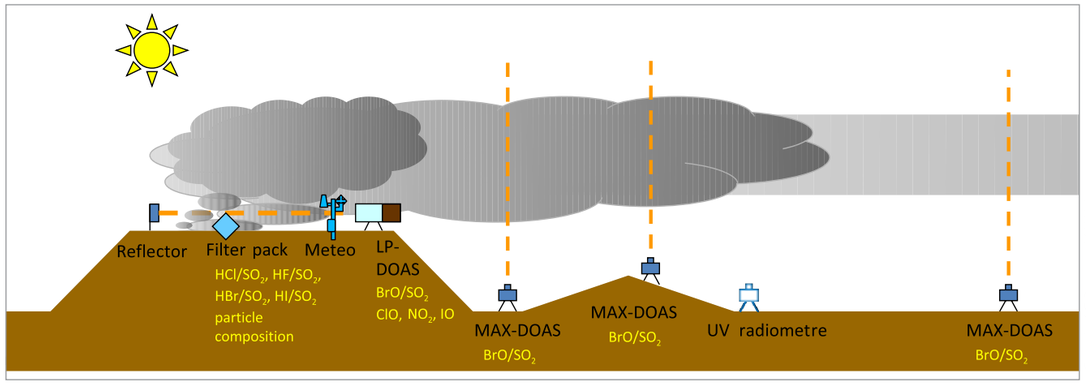
Volcanoes have always fascinated humans. On the one hand, they are an impressive sight with their spectacular beauty during fiery eruptions and their often attractive outlines and colourful designs during quiet periods. On the other hand, they represent an incredibly powerful force that is able to tear open the "stable" surface of the Earth, producing great heat and pushing out tons of material that pours down their flanks, or which hurls glowing rocks and gas several kilometres into the atmosphere.

About four billion years ago, our atmosphere mainly consisted of water vapour (H_2O), carbon dioxide (CO_2), sulphur and chlorine compounds (SO_2, HCl) as well as nitrogen (N_2), a little methane (CH_4) and ammonia (NH_3) – a mixture that is present in today's volcanic plumes. After the Earth had cooled sufficiently, the water was able to condense and CO_2 had been washed out to form carbonate sediments. Thus nitrogen, which is not soluble in water, gradually enriched in the atmosphere (it now makes up 78 percent of our present-day atmosphere). Major volcanic eruptions illustrate how gas emissions are still able to influence our climate, even if briefly. For example, the 1815 eruption of Mount Tambora on the Indonesian island of Sumbawa caused the "Year without a Summer" in 1816. Likewise, the 1991 eruption of Pinatubo in the Philippines, still remembered by many, lowered the mean global temperature by 0.5 °C the following year.

The history of gas measurements in and from volcanic plumes is relatively short compared to the history of seismic measurements. It has only been known for about 150 years that almost all volcanoes emit gaseous H_2O, CO_2, SO_2 and HCl, given in order of decreasing proportions. Gas measurements have become an established tool to obtain information on the interior of a volcano. Many measurements, however, can only be made with "in-situ" instruments or sampling apparatus, which means they have to be applied in close proximity to the volcanic crater. This is not only dangerous, it also prevents measurements during violent eruptive phases. The focus of the DFG project "Bromine chemistry in volcano plumes" addresses the question of whether the ratio between bromine monoxide (BrO) and sulphur dioxide (SO_2) inside the volcanic plume can be used as an additional indicator for volcanic processes. This would have the advantage that both gases can be measured with a relatively simple method known as differential optical absorption spectroscopy (DOAS), which can be carried out at a safe distance from the volcanic crater. The principle of the DOAS method uses the Beer-Lambert law and DOAS instruments can be very simple: often a telescope is used to collect sunlight scattered in the atmosphere from a particular direction and to feed it to a spectrograph. The scattered, apparently blue-white light from the sky, is in fact composed of many different colours (wavelengths).

Transfixed in front of the screen: measuring campaign on gas emissions from Mount Etna, the highest and most active volcano in Europe.

Illustration: AG Bobrowski / U Heidelberg



Graphic: AG Bobrowski / U Heidelberg

Finding out more about the composition of volcanic plumes: international collaboration to obtain new data.

A spectrograph is an optical instrument that splits light into its different spectral components and then measures the intensity of each wavelength arriving on the Earth. By aiming the motor-driven telescope in the direction of the volcanic plume, the sunlight first passes through the gases emitted by the volcano before it is measured. Every trace gas absorbs light of different, characteristic wavelengths/colours. By comparing the spectrum from the volcanic plume with that of the background sky, we see that the light intensity of certain wavelengths is lower. Analysis of the "spectra" (light intensities as function of wavelengths) provides information on the gases present in the volcanic plume, whereas the magnitudes of the individual intensity reductions indicate the gas concentration in the plume.

As mentioned above, the DOAS method can be used for precise measurements of trace gases from a safe distance, typically several kilometres away from the active crater. However, this requires that the gases absorb light in the wavelength range provided by skylight. DOAS measurements can detect not only sulphur dioxide but also halogen oxides in volcanic plumes. Key factors for the information about the volcanic system are the amount of gas blown into the atmosphere each day by the volcano and the composition of the emissions. The DOAS method enables simultaneous detection of different trace gases and their amounts. The relative concentrations in the plume depend not only on the conditions inside the Earth, but also on the chemical processes on the surface and in the atmosphere.

Today it is assumed that halogens are considerably more soluble in hot magma than sulphur, and sulphur is appreciably more soluble than carbon dioxide. If outgassing takes place as the magma rises from great depths (which also means from higher to lower pressure), carbon dioxide is released first. As the magma continues to rise, sulphur is released into the gas phase as well, and will afterwards be followed by the first halogens. Thus, as the magma rises from the depths, an initially low ratio of halogens to sulphur is observed. This applies to chlorine and fluorine, at least; very little is known about bromine at present. If the partially outgassed magma rises even further towards the surface of the Earth, the lower pressures cause larger amounts of halogens to outgas, and the halogen/sulphur ratio in the emissions starts to increase.

Although this simplified example only occurs under special conditions, it illustrates how the gas composition can be used to obtain information on the processes taking place inside the Earth. Researchers thus regard volcanic emissions as "messages from the depths" that

Illustration: AG Bobrowski / U Heidelberg

Impressive: The 3500 metre-high Nyiragongo volcano in Central Africa boasts an active lava lake.

provide indirect information on what is happening deep under the Earth's surface. This is comparable to the hieroglyphs, which also had to be decoded and understood.

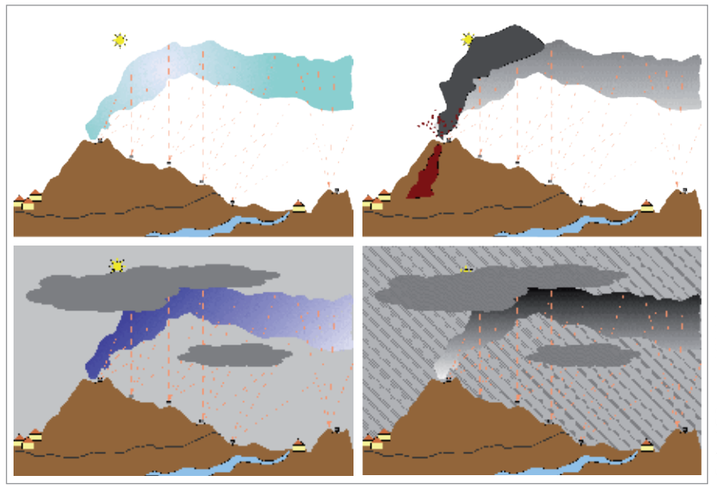
Bromine monoxide was first detected in volcanic plumes in 2002 at the Soufrière Hills volcano on the Caribbean island of Montserrat. This result was quite sensational at the time because scientists did not expect to find a raft of interesting atmospheric chemical reaction cycles in volcanic plumes. This phenomenon has been measured many times since then, proving that Soufrière Hills is not an exception. Detection of bromine monoxides in volcanic plumes means that there is considerably more chemistry taking place in the interactions between volcanic gases and air from the surroundings than was assumed ten years ago.

Although it is relatively easy to measure bromine monoxide (BrO) and sulphur dioxide (SO_2) at a safe distance from the volcano, BrO is a very reactive gas. A measuring campaign on Mount Etna in Sicily in 2004 revealed that BrO is formed in the volcanic plume at the moment when the volcanic gases mix with the surrounding air. It is thus important to understand the relationship between BrO and the total emitted bromine and how meteorological factors influence the BrO formation rate. Another important question is to determine the time period during which the gas remains stable. The answers to these questions are the goal of the DFG project.

This knowledge will enable BrO to be used as an indicator of volcanic changes. However, there are initial indications that the BrO/SO_2 ratio provides information on the state of the magma inside the volcano. This was demonstrated by the first sensitivity studies and measurements of Mount Etna (2006–2009), during which the volcano erupted twice (2006, 2008). In both cases, the volcano erupted after the BrO/SO_2 ratio had increased several months before the eruption and then dropped before the eruption started.

These DOAS measurements will now be continued, supplemented by intensive in-situ focal campaigns to measure gases and aerosols, particularly at the crater, in order to determine the exact composition of the volcanic emissions, including the total bromine flux. At the same time, meteorological and solar insolation data are also being collected because they are important for the chemical reactions.

The first intense campaign was carried out in Central America in 2011. In February, measurements were carried out on Mexican Popocatepetl in collaboration with the National Autonomous University of Mexico. In March, further measurements took place on the volcano Masaya in Nicaragua together with colleagues from the Instituto Nicaragüense de Estudios Territoriales (INETER) and English scientists from Oxford and Norwich. These two volcanoes, Popocatepetl and Masaya, are located in two different climate zones and emit their gases into two very different atmospheric layers. On Popocatepetl at an altitude of 5400 metres above sea level, the air is very thin, it is chilly (the temperature drops below freezing at night) and the relative humidity is low. In contrast, at the altitude of 600 metres on Masaya, the atmospheric humidity is very high, even during the dry season, with temperatures ranging between a little over 30 °C during the day and about 20 °C at night. It was also possible to measure the absorption of volcanic gases from the Masaya volcano during the night using an artificial light source. In June/July 2011, an extended measuring campaign was conducted on Sicilian Mount Etna to study this volcano in great detail over a period of more than one month. Similar to Masaya and Popocatepetl, measurements were made during the day at different distances from the crater.



Grafik: AG Bobrowski / U Heidelberg

Four scenarios, one research goal: Gas emissions are being studied in conjunction with changing meteorological conditions and volcanic activity phases.

The initial results have already been presented in September 2011 at the 11th international workshop on volcanic gas measurements that was held on the Kamchatka peninsula, Russia. This opportunity was also used to carry out spot measurements on two nearby volcanoes (Gorely and Mutnovsky), which have barely been investigated so far.

Thanks to additional project funding from the United Nations, we were able to pay two visits to the Nyiragongo volcano in the Democratic Republic of Congo in 2011. Mount Nyiragongo, a 3500 meters high volcano in tropical Central Africa, has the world's largest active lava lake, where the height of the lava level can be directly observed and correlated to the changes in the gas composition.

After the many measurements in 2011, work in 2012 focussed on detailed evaluation and interpretation of the data. In September 2012, we spent an extended period on Mount Etna and carried out further measurements under very unsettled meteorological conditions.

Interim status of the project work and data mining so far: At all three volcanoes – Popocatepetl in Mexico, Masaya in Nicaragua and Mount Etna in Italy – the automated DOAS instruments were re-installed or restored so that they can now again continuously record data to provide longer time series. We hope to achieve a more detailed understanding of these volcanic messages sent from inside the Earth. At least on Mount Etna it is very likely that we will be able to record an eruption during the project because the volcano generally makes itself heard every one to two years.

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Philipp Richter

Intergalactic Winds

Stars contain only a small fraction of the visible matter. Forming the largest reservoir are filament-like structures made of gas, which cross the entire universe. Research of these structures reveals a great deal about the formation and development of galaxies.

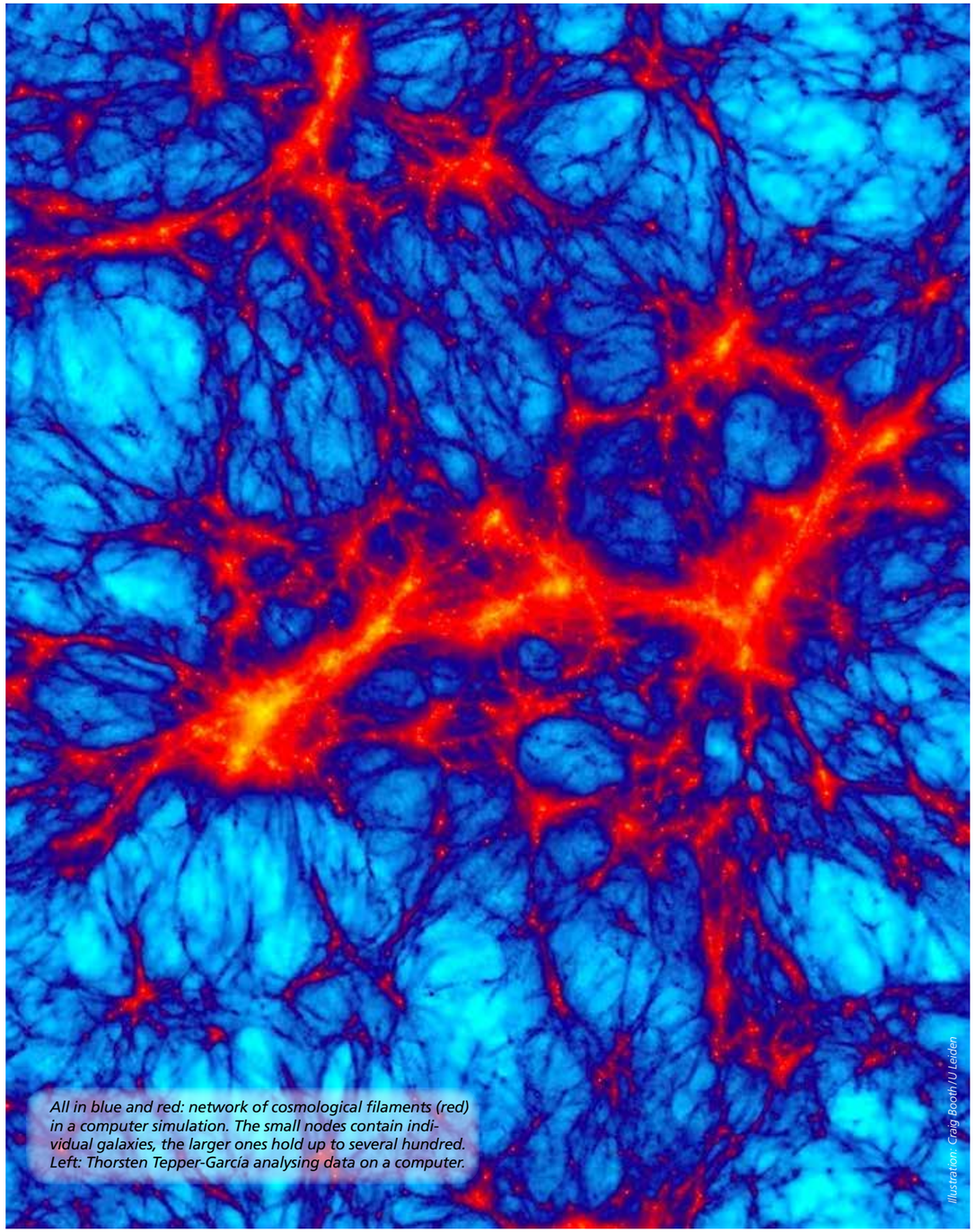
What is the universe made up of? This fundamental question has always occupied astronomers and continues to do so even today. Over the past two decades, researchers have made great progress towards answering this question. As a result, we now know with great certainty that the universe is expanding at an accelerating rate – the Nobel Prize in Physics was awarded for the measurement of this accelerated expansion in 2011. And it is becoming increasingly clear that the dynamics of this expansion are determined largely by energy and matter components, the nature of which remains in the dark – in the most literal sense. It is not without reason that we speak of "dark energy" and "dark matter" – not only in scientific contexts.

"Ordinary" matter (in technical jargon: baryonic matter) is the matter that we are able to directly measure and which consists of atoms and molecules. It makes up no more than 4 to 5 percent of the cosmic reservoir of matter and energy and is, thus, of nearly no consequence to the dynamics of the expansion of the universe. For astronomers, baryonic matter is nevertheless of central importance, because it is the baryons, which we can observe in the form of planets, stars and galaxies in the night sky, that provide us with information on the properties of the cosmos.

Illustration: AG Richter/U Potsdam

According to current knowledge, the first light elements (hydrogen and helium) formed shortly after the Big Bang and, through combination with the electrons, a neutral gas mixture arose. Approximately 200 million years after the Big Bang, the first stars in the universe developed from this "primordial gas" as a result of gravitational instabilities. Using state-of-the-art telescopes, astronomers are today on the lookout for light from these stars. As the force of gravity pulled the gas into increasingly dense, filament-like structures ("cosmic filaments"), the first larger galaxies formed, thereby enriching the surrounding intergalactic gas with the heavy elements contained in the stars. But galaxies inject not only heavy elements into the surrounding gas, but also energy in the form of galactic winds. This heats up the gas. Such winds are created when the concentrated release of energy from supernova explosions of massive stars drives the surrounding gaseous matter out of the galaxies.

The intergalactic gas in the cosmological filaments can actually be observed: the portion of neutral hydrogen present in the gas absorbs the light from bright objects (quasars) located behind the filaments. If one breaks down the light from quasars into its spec-



All in blue and red: network of cosmological filaments (red) in a computer simulation. The small nodes contain individual galaxies, the larger ones hold up to several hundred. Left: Thorsten Tepper-García analysing data on a computer.

Illustration: Craig Booth/U Leiden

tral components, the intergalactic gas structures are revealed through corresponding line absorption in the so-called Lyman-alpha line. In other words: because each of these filaments takes part in the cosmic expansion and has its own redshift and position in the spectrum depending on its distance to us, the absorption signatures of these gas filaments appear to us as a "forest" of absorption lines in the spectrum of the background object.

This intergalactic "Lyman-alpha forest" was first observed in the 1960s. From the frequency of the lines in the spectrum and their thicknesses, it is possible to estimate the total amount of gaseous matter contained in the cosmological filaments.

Spectra from very distant quasars show that, in the early universe (with very large redshifts), more than 95 percent of the baryonic matter is in the form of gas in the cosmological filaments. At this time, only a few stars and galaxies have formed in the universe from the gas. In today's universe (with small redshifts), the portion of baryonic matter in the Lyman-alpha forest has, in contrast, been reduced to approximately one third without a comparable mass having been converted to stars and galaxies. This puzzling observation begs a simple question: where are the baryons from the gas?

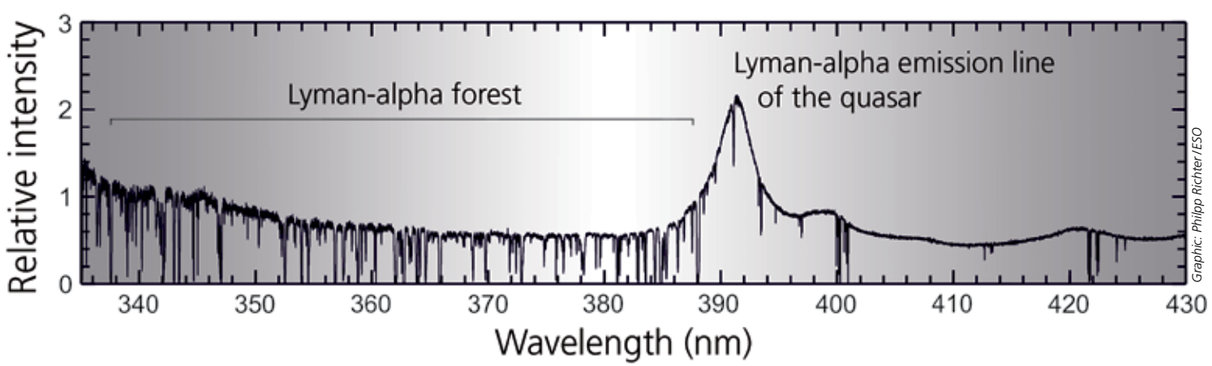
The most plausible explanation for the disappearance of the Lyman-alpha lines in the spectra of quasars is that a portion of the gas is heated as a result of the continuing structural development, causing the percentage of absorbing neutral hydrogen to decrease as the age of the universe increases. This was deduced by astronomers in the late 1990s from cosmological computer simulations in which the distribution and physical properties of the intergalactic medium were modelled. According to this, it is not the gas that disappears, but rather the (neutral) portion of the gas that absorbs the light. As a result of the heating of the gas, the hydrogen is nearly completely ionised.

This means: nearly all hydrogen atoms lose their only bound electron. This, in turn, means that no line transitions can occur in the gas and the ionised hydrogen atoms (protons) become invisible at the low particle densities in the intergalactic gas. The gas is nearly 100 percent transparent. At least part of the energy necessary to heat up and ionise the hydrogen comes from the gravitational binding energy of the gas that is released when it further accumulates into the cosmological filaments. According to the simulation, a new so-called "warm-hot" intergalactic gas phase forms that can apparently be verified only with difficulty.

The objective of our DFG-funded project was to study this process, which appears to be very important for the understanding of the development of our universe. Using the latest generation of cosmological computer simulations, we have studied in detail what physical conditions are present in the warm-hot intergalactic matter, what connection exists between this gas and the surrounding galaxies and how it can be observed. The results from the simulations were then compared to the observed spectral data from the Hubble space telescope.

One prediction from previous studies was that the chemically enriched warm-hot intergalactic gas should contain traces of metal ions, the electric line transitions of which are visible in ultraviolet spectra of quasars. In particular, the line doublet of the fivefold ionised oxygen

Intergalactic gas in the filaments produces a "forest" from absorption lines in the optical spectrum of a distant quasar.



Graphic: Philipp Richter/ESO

Illustration: NASA

The Hubble Space Telescope also detects the ultraviolet spectra of quasars.

(OVI) was considered here to be the most promising candidate for verifying the warm-hot intergalactic gas component. Many OVI absorption lines have actually been detected in the spectra of quasars. But their interpretation in a physical regard has been found to be difficult. This is due, above all, to the fact that the ionisation energy required to form the fivefold ionised oxygen is also made available by processes other than gravitational heating, such as high-energy radiation. So, what can we actually learn from the OVI absorption lines?

With the help of the cosmological simulations computed by our colleagues Professor Joop Schaye and his team in Leiden, it was possible to study in detail what type of absorption lines the warm-hot intergalactic gas leaves behind in the signatures of the quasar spectra and what role the OVI lines play here. Under the direction of Dr. Thorsten Tepper-García, synthetic absorption spectra were calculated from the simulation boxes and statistically evaluated for this purpose at our institute in Potsdam. Most important result: the line doublet of the fivefold ionised oxygen is not a good indicator for the number and distribution of the baryons in the warm-hot intergalactic gas; instead, OVI traces chemically enriched gas heated by galactic winds.

The study shows that the heavy elements are very inhomogeneously distributed in the intergalactic matter. Hot, chemically enriched gas, which can be observed with the aid of OVI absorption, is located primarily in the immediate vicinity of galaxies. The majority of the baryonic matter is, however, not located here but is rather far from the galaxies with a considerably lower percentage of heavy elements. There, the oxygen content is too low and the gas on average too hot to cause measurable OVI absorption. The spectra produced by the simulations are in excellent agreement with the spectra observed with Hubble. From this we conclude that the simulations realistically represent the actual conditions in the intergalactic gas.

Conclusion: the vast majority of the warm-hot intergalactic gas cannot be verified with current observation instruments. At first, this result appears to be a sobering one. But it does bring clarity to the interpretation of absorption spectra that can currently be collected with the new UV COS spectrographs on the Hubble space telescope. Moreover, this understanding leads to a number of further realisations related to the circulation processes of chemically enriched gas in the vicinity of galaxies. The understanding for the diffuse intergalactic gas component in the universe will benefit from this.

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Lena Krull

Illustration, LWL-Medienzentrum Westfalen

A Very Public Ritual

In Wilhelminian Germany the congregation of tens of thousands of Catholics in processions through the streets of Prussian towns was a bold expression of religious commitment within a nation fraught with political and social tensions.

When, in May 1845, cries of "The Protestants have taken the flag!" echoed through the centre of Essen, tempers were quick to flare. In the ensuing pandemonium, the Corpus Christi Procession degenerated into street fighting. Stones flew as the police came under attack and the town hall was besieged. Only the timely intervention of a Catholic minister assuaged the mob. Halted in its tracks, the festive procession was unable to proceed, and the feast day concluded with numerous arrests. The Elberfelder Zeitung described the events as "a scandal reminiscent of the wildest moments of anarchy and lawlessness".

But such outbursts of violence were few and far between at the Corpus Christi Procession. However, conflicts of this kind offer historians revealing insights into denominational relations within communities. The riotous scenes in Essen were not in fact entirely unexpected: as later eyewitness accounts testify, rumours that Protestants would steal a flag abounded prior to the day. What then was the source of these tensions between the two Christian communities? In the second half of the nineteenth century, industrialisation resulted in rapid population growth in Essen and the wider Ruhr area. The size, influence, and significance of various denominational communities shifted in many cities. In the wake of these changes, religious tolerance gradually gave way to sectarian conflict. In Essen tensions resulting from conversions to Catholicism and the economic and political disadvantages suffered by Catholics were compounded by conflicts relating to interconfessional marriages (Mischehen).

In the 1830s the Prussian state and the Catholic Church renegotiated their positions on the issue of "mixed marriages" and the religious confession of any offspring born in such marriages. The fact that it fell upon the state to represent the position of the Prussian Evangelical State Church further complicated this situation. The church and state were intrinsically linked in 19th century Prussia, and the Prussian king was also the head of the Prussian Union of Churches. Accordingly, the addition of the predominantly Catholic territories of Westphalia and the Rhineland – including the Ruhr area – to the Prussian realm in the early 19th century presented a significant challenge. In this context, the procession of the faithful through the streets of Prussian towns was more than an expression of religious devotion. Rather, such events were closely tied to political affairs.

A doctoral research project at Münster's Cluster of Excellence for Religion and Politics in Pre-Modern and Modern Cultures has examined the role and significance of Catholic processions in the Prussian cities of Berlin, Wrocław, Essen, and Münster. Looking beyond more general perspectives on 19th century religious history, the project focusses on local power relations and the life of religious communities. The pilgrimage to the Holy Robe in Trier in 1844 highlights the issues at stake and reveals the controversial nature of public expressions of Catholic piety during this period. Hundreds of thousands of Catholics travelled to Trier to venerate the robe that Jesus was said to have worn at his crucifixion. The pilgrimage was discussed widely in the German press. Protestant and liberal pundits issued scathing critiques and branded the pilgrimage a 'superstition'. Frequently, it was the public nature of this religious practice which critics found to be objectionable and considered a provocation.

The controversy, which became a matter of national debate, was also felt at a local level in Essen. Against the objections of a Catholic priest, a pamphlet directed against the pilgrimage soon began to circulate. The Catholic community, in turn, used the Corpus Christi Procession as an opportunity to voice their support for the pilgrimage by displaying flags bearing images of the Holy Robe. In the aftermath of the procession of 1845, an eighteen-year-old eyewitness from Essen reported the following: "I saw a large man wrench the flag with the Holy Robe from the hands of a girl and carry it off in the direction of the town hall."

This theft was to form the crux of the ensuing conflict: Although the Catholic clergy drew on eyewitness accounts in an effort to prove that a flag had indeed been stolen temporarily, no evidence was found to confirm the loss of a flag during the procession. Following the court investigation, only those individuals were convicted who were proven to have committed acts of violence during the disorder. As noted by the priest in his report to the Vicar General of the Archdiocese of Cologne, fourteen men were sentenced to prison terms ranging from five months to four years.

Catholics in Essen were insulted by this outcome. In their view the court, along with the city's Protestant mayor and police force, was prejudiced and pro-Protestant. For historians the question of whether a flag was in fact stolen from the procession is of less interest than the capacity of a single rumour to trigger

Traditionally an altar was positioned opposite the monument on Essen's Burgplatz on the day of the procession.

Illustration: Private

Illustration: Münsterarchiv Essen

Regulations for the Corpus Christi Procession in Essen (1893): The order of the participants is detailed at left, their positions during the final blessing on the right.

such unrest. The public character of the procession made it all the more likely that tensions between the city's Christian communities would erupt into open conflict. Tempers cooled again in the following years and the violent excesses of 1845 were not repeated in Essen.

While the Kulturkampf – an extended conflict between the Prussian state and the Catholic Church in the 1870s – led to violent confrontations in many cities, this was not the case in Essen. The Kulturkampf itself was part of a wider debate over the role of religion and, in particular, the Catholic Church within the modern state. In 1870 this conflict culminated in the foundation of the German Centre Party (Deutsche Zentrumspartei) – a Catholic political party. The Chancellor of the German Empire, Otto von Bismarck, became a vigorous opponent of the Centre's political vision. In a coalition with the Liberals, Bismarck eventually came to turn on the Catholic Church as a whole and sought to curtail its influence on public life. This policy met with resistance and protests by the Catholic Church. The long-standing differences between the denominational communities, which boiled to the surface in Essen during the tumultuous events of 1845, were reshaped and heightened by the Kulturkampf.

The subsequent events in Münster were a case in point: in 1876 the authorities in the Westphalian university town forbid school pupils from participating in the Grand Procession staged each year since the 14th century. But when the procession passed through the town on a Monday, over 2000 school pupils skipped class in an act of collective defiance. Their parents rallied together to appeal against the fines imposed on them and the Prussian Ministry of Culture was forced to intervene in the conflict after several months. In the following year,

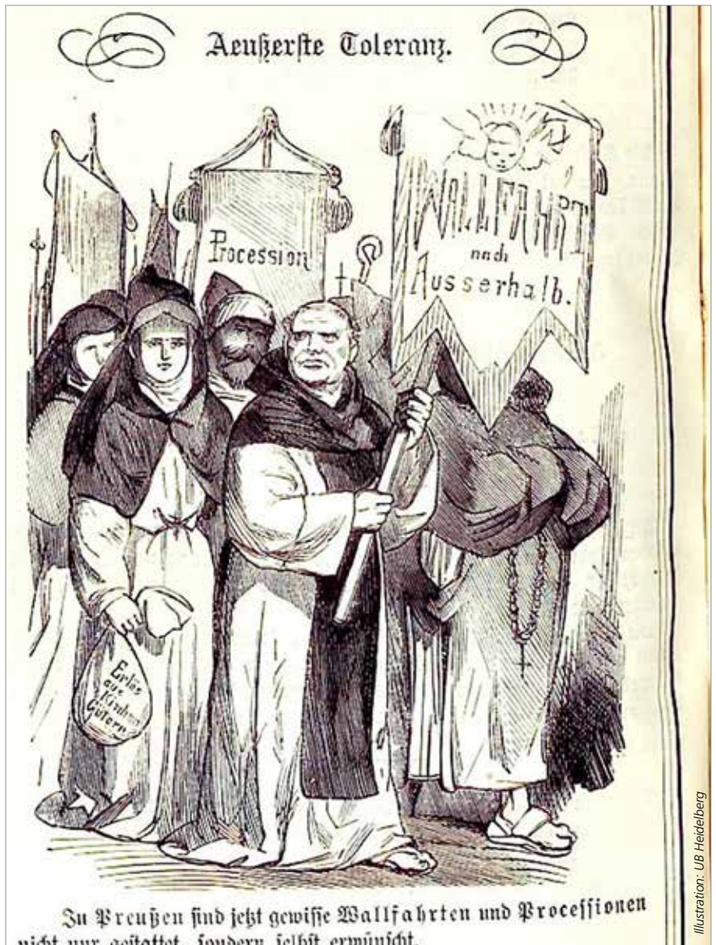

Illustration: UB Heidelberg

"Aeußerste Toleranz" (Utmost Tolerance)*: This scathing commentary on the laws governing religious processions in Prussia was published in the satirical magazine "Kladderadatsch" in 1875.*

the town authorities championed the pupils' right to participate in the procession once more, noting that the event was "the only major popular festivity held in the city to aspire to higher ideals".

In the wake of the Kulturkampf Catholic communities seized on processions, which were accompanied by flags, ornate altars, festive costumes, hymns, a monstrance and incense bearers as a means to express their religious convictions in public. Essen's Corpus Christi Procession became a festival for the senses under the German Empire. A planning committee, established in the 1880s, ensured that this remained the case. Documents held in the parish archives show that priests and parish members coordinated the course of the procession, the various participating groups and their sequence.

Print copies of the regulations governing these events, which attracted up to 25,000 participants, document the precise order of events at the processions, which circled the town centre along broad avenues. According to reports in Essen's daily newspapers, the town's tram service suspended its operations for several hours to allow the passage of the procession, and rubbish collections were postponed until the following day. The procession was followed by a concert in the city's municipal gardens – just one example of the secular amusements that frequently attended such religious festivities.

The popularity of the procession was due not least of all to the active involvement of the city's various clubs and societies. A broad spectrum of associations participated in the procession, ranging from the Knappenverein (Miner's Society) to the Jungfrauensodalität (Sodality of Our Lady), often clad in uniforms or attire associated with their organisations. The festival offered members of the Catholic Church the opportunity to share their identity with a wider audience. "Eucharistic Honour Guards" established for the occasion accompanied the Procession in their magnificent uniforms, offering the Blessed Sacrament symbolic "protection" as it made its way through the streets. From 1899 onwards, the central altar was erected on the Burgplatz opposite a new equestrian statue of Kaiser Wilhelm I. The symbolic import of this gesture was clear: Prussia and Catholicism no longer formed an antithesis. Indeed the two formed a conspicuous symbiosis at the Procession.

These examples illustrate the close ties that existed between the political and religious aspects of municipal processions in the 19th century. Indeed, these religious celebrations continued to serve as sites of political expression far into the 20th century. In Münster, for example, participants of the Grand Procession prayed for German soldiers and for victory throughout the First World War; during National Socialist rule – following the breakdown of relations between the regime and the Catholic Church – the participants made no pretence of concealing their allegiance to the bishop and the Church.

Illustration: Archiv Ruhrmuseum Essen

Participants take up their positions as the Blessed Sacrament leaves the church.

Lena Krull M.A.
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The Power of Music

Physician and musician Eckart Altenmüller talks about the goose-bump factor in music, the wonder of neuroplasticity and the potential for sound-assisted therapies. An expert interview

Illustration: DFG / Ausserhofer

Music is much more than just a pleasant pastime or a personal passion: it arouses emotions, evokes memories and builds bonds – music touches people. But how and why does it have that power? The neurologist and musician Professor Eckart Altenmüller is a leading authority in the neurophysiology and neuropsychology of music. Recently, in early 2012, he was portrayed in a "New York Times" article. "german research" met with Altenmüller at his institute in Hanover, encountering a scientist who in one person embodies a neurologist's seriousness, a doctor's empathy and a musician's presence. An interview with an "ambassador of music".

german research: Professor Altenmüller, what would a world without music be like?

Altenmüller: I think there would be less joy, and fewer experiences of community or significant emotional experiences. The world would be a lot colder and more isolated. Music keeps us together in many regards – in unspoken, subtle ways, often working in the background.

You are a neurologist and musician. What do you see as your main role?

I state "physician" as my profession when checking in at a hotel. In such situations I see myself primarily as a scientist. At the same time I am a professional musician. I move back and forth between the two worlds.

How do you experience music?

Nowadays I listen to music very selectively, music that enriches my inner experience, that opens up to me nuances of emotion and that I feel within. I love Lieder by Schumann, for instance. When playing myself, I usually have a flow experience already while practising. I can completely forget myself, even family obligations sometimes.

Why is music said to be generated in the head?

Listening to music – and this is important to me – is an active process that generates meaning. Listening triggers widespread activations in the auditory cortex, which is the part of the cerebral cortex where auditory stimuli from the inner ear are processed, and in the frontal and parietal lobes. Music is a game of expectations, building them up and then in a certain sense disappointing them. We more or less automatically continue melodies and rhythms in our heads. Our interest is aroused keenly when these patterns then take an unexpected turn. Music is generated in the head; at a neuronal level it is an activity involving a highly intricate network.

You are referring to the emotional effects of music, a subject that you have studied in a DFG project …

… in a large number of experiments and with the aid of subjective and objective measures. First we ask our subjects to relate their feelings immediately as they listen to music. They sit comfortably in a chair and can report their emotions non-verbally using a joystick. We later correlate the listener's subjective rating with the musical impression made by the piece, with details from the listener's life, and with the structure of the music.

We also take intermittent readings of objective parameters such as galvanic skin response, pulse, blood pressure or skin temperature, and we additionally record brainwaves. In this way, we attempt to record the objective reactions within the nervous system accompanying, for example, the experience of the thrill of awe. Finally, we compare the objective and subjective parameters in the hope of discovering regularities.

What did you discover?

We had the ideas that, in music, archetypal forms had to exist that are universal. Take for example the beginning of Brahms's Third Symphony, when the brass chord resounds increasingly brighter and louder, immersing the listener in a torrent of sound. It leaves me with goose bumps. I said, "That must affect everyone in the same way!" But that is not what we discovered. It turned out instead that what people feel is very much dependent on their individual experiences as a listener.

Your name doesn't have to be Daniel Barenboim to relate to the power of music. How can you explain the "goose-bump factor"?

Initially, goose bumps are a very primordial mechanism for thermoregulation. You get goose bumps when it gets cold. In the history of evolution, the mechanism was probably related to generating internal body heat. That is suggested by the goose-bump phenomenon among primates, a subject currently under study by the DFG Research Unit for acoustic communication. When separated from her infant, the mother monkey utters a separation cry that is then heard by the baby, whose bodily hair stands up – and warms it. This form of social interaction was passed on to humans only much later. In the meantime we also know that goose bumps are associated with the release of dopamine and endorphin, which supports the ability to remember. In other words, experiencing goose bumps reinforces your musical memory.

What is required in order to experience goose bumps?

We surveyed and observed hundreds of test subjects in the hope of identifying a "goose bumps recipe". We discovered that an interesting structural change always precedes the experience of the thrill of awe. That can be the entry of a new instrument, or a new tone colour, a change in volume or certain harmonic progressions. Such a change is a necessary but not sufficient precondition for the listener to experience goose bumps.

Ad Personam

Professor Dr. med. Eckart Altenmüller was born in Rottweil in 1955 and studied medicine at Tübingen, Paris and Freiburg. He completed his doctorate, was licensed to practise medicine and completed specialist training before qualifying as a university lecturer in neurology in 1992. At the same time he pursued studies in music with a major in flute and graduated with a fine arts degree. Since 1994 he has been head of the Institute of Music Physiology and Musicians' Medicine at the Hanover University of Music, Drama and Media. He is also head of the national outpatient clinic for musicians with medical issues. His research interests are focussed on the foundational aspects of brain physiology related to music performance and perception. In projects largely funded by the DFG,

Illustration: IMMM Hannover

Altenmüller has investigated cerebral activity associated with learning music and sensorimotor aspects of playing the piano, while he has also studied changes in music perception among stroke patients and issues relating to emotions in acoustic communication; he also does research in special disorders affecting musicians. Apart from research, teaching and practising medicine, Altenmüller performs regularly in public as a flautist.

www.immm.hmtm-hannover.de

What are the benefits for people who play music?
The findings are unequivocal and have been replicated many times over: with children who play music at an early age – whether they play the violin, the piano or another instrument – certain regions of the brain become enlarged compared with non-musicians. Specifically these are the motor regions, the auditory regions and the neural fibres responsible for interconnecting the two cerebral hemispheres in a network. Neuroplastic modifications result from playing music regularly.

While on the topic of neuroplasticity, did any of the research findings especially surprise you?
Yes, definitely. How quickly modifications take place. You find neural links even after one hour of piano training, i.e., a measurable increase in coherence of neural networks in the brain's auditory and motor regions. That's how quickly the first data highways are built. That was an utter surprise to discover the first time.

Violin, bow and sensors in the service of science: The movement patterns of André Lee, physician and musician, are recorded as he plays.

Illustration: MMM Hannover

Here's a burning question that interests not only parents: does music enhance intelligence?
Certain facets of cognitive intelligence are fostered by playing music. These include the abilities to learn patterns and form strategies. A more important aspect is the development of emotional competence, the training of abilities useful in a daily context as well: memory, coordination, empathy. Musicians rate better in these areas.

How, in contrast, does musical perception change with brain disorders, after a stroke for example?
You are referring to our DFG project on the topic. About 70 percent of all stroke patients have a disturbed perception of music – that surprised us greatly. This indicates that music activates a broad neural network that correspondingly reacts sensitively to any disturbance. But the good news is that only about 15 percent of patients show related deficits after one year. It is interesting to observe that the deficits do not depend on which cerebral hemisphere was affected, as was thought for a long time.

Is that an argument for offering music-supported therapy to stroke patients?
Yes, it is very helpful. We are currently working on another large cooperative study. The rehabilitation of stroke patients, even of those with no experience playing music whatsoever, progresses much more quickly and better when we sit them down at a piano to train their fine motor skills and provide them with immediate feedback while practising.

What "occupational illnesses" do musicians have to cope with?
I practise as a neurologist specialised in disorders affecting musicians. Mostly people experiencing serious pain come to my office, for example, violinists with pain in the right shoulder that is resistant to treatment, or cellists experiencing pain in the fingertips of the left hand. I see mostly patients with movement disorders, who lose fine motor control of their instrument, in other words people with "musician's dystonias". With the aid of these patients from all over Germany, we are also conducting basic research …

… which also has practical value?
Of course! We have made people aware of the disease in recent years, advised patients on treatment options, and we have initiated a prevention programme at the music universities. Still, musician's dystonias will continue to be a challenge.

Whether as a therapist, researcher or performer – music is the focus of your life. What is the underlying mission?
For me it is important that we do not see music just as a subject of research and limit it to that, but that we regard it as a sphere of inner experience and a way of establishing deep cultural bonds. It worries me to see the culture of playing music coming under pressure in many areas. That is one of the reasons why I like to go out in public and hold popular lectures on music, even when colleagues turn up their noses. I may be able to arouse someone's enthusiasm for music by explaining and clarifying the relationships involved – and evokes a joy that echoes afterwards.

Interview:
Dr. Rembert Unterstell
Publishing Executive Editor of "german research"

Stefan Schuster

Gotcha

How are decisions made? And what happens in the brain? The tiny cellular networks in archerfish are giving researchers surprising answers to some fundamental questions.

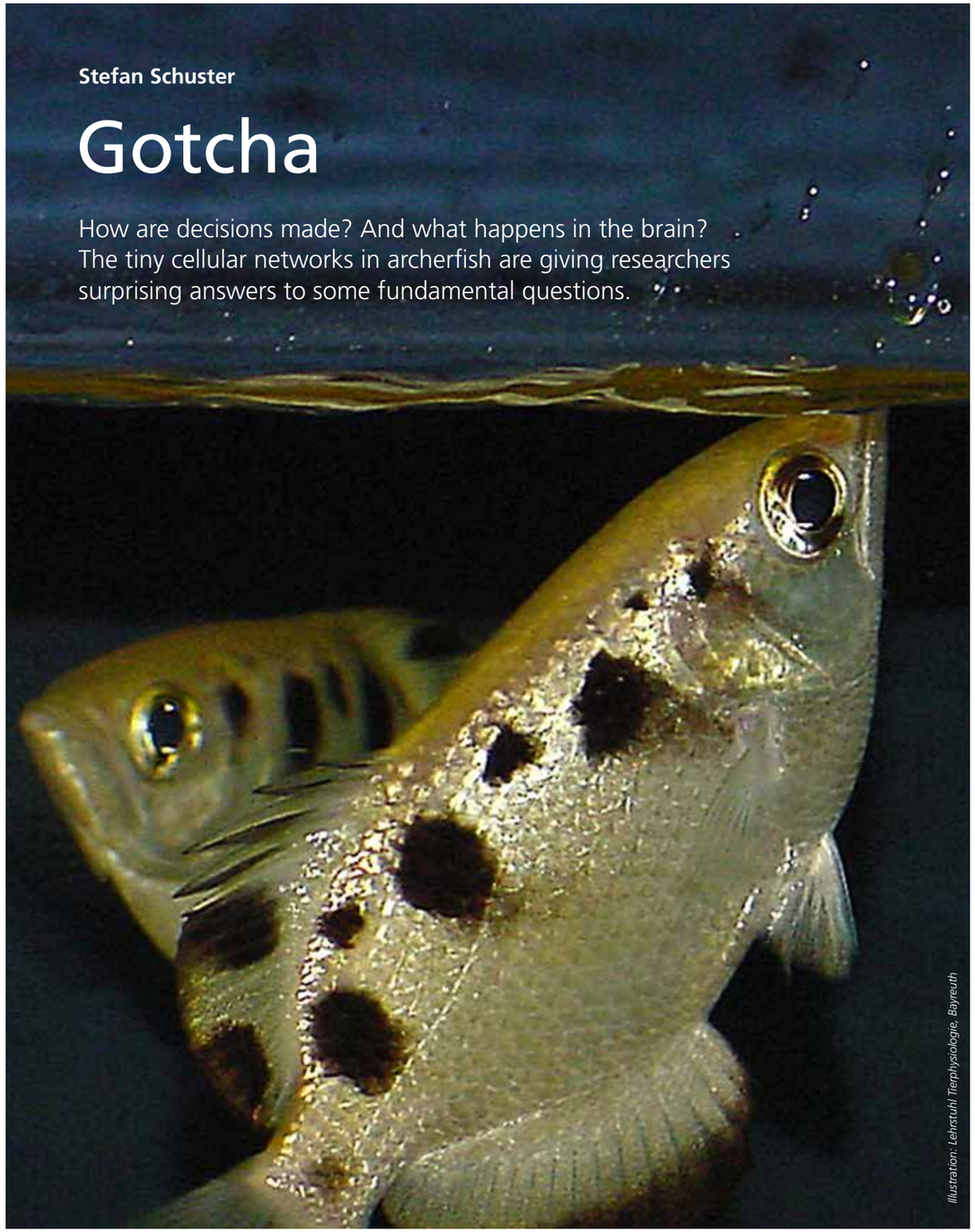


Illustration: Lehrstuhl Tierphysiologie, Bayreuth

The innumerable decisions we make every day range from the trivial to the momentous; however, they all have one thing in common: currently available information is combined with information stored in the past in order to choose the most suitable action from a range of alternatives. What happens in our brain during decision-making is a fascinating and popular research topic. In which form can rules that are decisive for the success or failure of an action be incorporated into the respective decision, and how are "obsolete" rules updated?

Researchers have much experience using brain scans to observe the activity of individual areas of the brain during decision-making. However, it is much more difficult to elucidate the fundamental mechanisms on which the phenomena are based at the level of the individual cells in the neuronal networks. This involves monitoring subcellular processes of many millions of cells – a mammoth problem and currently one of the greatest challenges for neuroscientists. A Koselleck Project of the DFG is sponsoring what appears at first sight to be a very unusual approach to studying mechanisms at the cellular and network levels.

Illustration: Schuster, Lehrstuhl Tierphysiologie, Bayreuth

Unprepossessing only at first sight: A network of just a few cells, which are found in each individual fish, is used as a model for decision-making processes.

The starting point was the search for a system in which complex decisions that are flexibly adaptable to environmental rules and which are made by a small and – if possible – readily approachable network in which each neuron could be individually identified. Though unlikely, such a system was indeed found in the hunting behaviour of fish and in their associated decision-making processes. What are the special features of this model system? The decisions are made extremely quickly. They are complex, plastically adaptable and are mediated by a small neuronal network that is approachable at the cellular level. Furthermore, the information on which the decision is based can be fully controlled experimentally.

Studies revealed the best constellation in a fish with a rather unusual hunting behaviour: archerfish. These fish are native to the mangrove swamps in the Indo-Pacific region and are renowned for their ability to shoot down prey located above the surface of the water and at large distances of up to two meters using a single directed jet of water.

The fish shoot from a lateral position so that the dislodged prey falls ballistically onto the surface of the water. This effective hunting technique means that the fish have to observe the initial motion of prey hit by another member of the shoal and then implement this information into the correct fast-start programme as quickly as possible, bringing the fish onto the correct heading and with the correct take-off speed so that it arrives at the prey just as it hits the water. Not only does this (decision-making) process have to be fast, it also has to be accurate, otherwise the prey will be bagged by a competitor. Surprisingly, these start decisions do not need any a priori information on the location, initial height, direction and speed of the moving prey. As the prey starts to move, the fish needs only a very short time to acquire all the necessary information to determine the landing point, and thus to select an adapted fast-start programme. This also allows it to adapt its start. This also means that the information required for the decision can be fully controlled under experimental conditions. It is also possible to confront the fish with all sorts of different combinations of information that can be varied from test to test. For example, researchers can find out whether the fish chooses its starts according to a rule associating the individual pieces of information with the landing point. In the experiments, dead flies are blown off the upper surface of a non-transparent platform with a fixed, but randomly chosen horizontal and vertical speed (0–1.5 meter per second). In addition to the basic information – starting point of the moving prey, speed, direction – the fish must have internalised a general rule: the law of falling bodies, with and without air friction.

The choice is finely tuned and is certainly not just a simple "yes/no" decision. Archerfish are not only able to select the correct turning angle from the whole range, but also the suitable take-off speed. Depending on the remaining time and distance to the landing point, they select a speed that allows them to reach the prey at the right time

Below: Fast-start decision? This experimental setup is used to confront archerfish with various starting situations.

Illustration: Machnik, Lehrstuhl Tierphysiologie, Bayreuth

without having to accelerate, thus conserving energy.

The rule on which the decision is based – once programmed – is flexible and can be adjusted when external rules change. For example, if the fish are hunting a falling prey without air friction, the initial motion of the prey and the subsequently activated motor programme follow the fundamental law of a falling body without air friction. If the physical relationship between the landing point and the initial motion is changed, the decision made by the fish is adapted. A further remarkable finding is that the fish can adjust their start decisions according to obstacles that would lie in their future path.

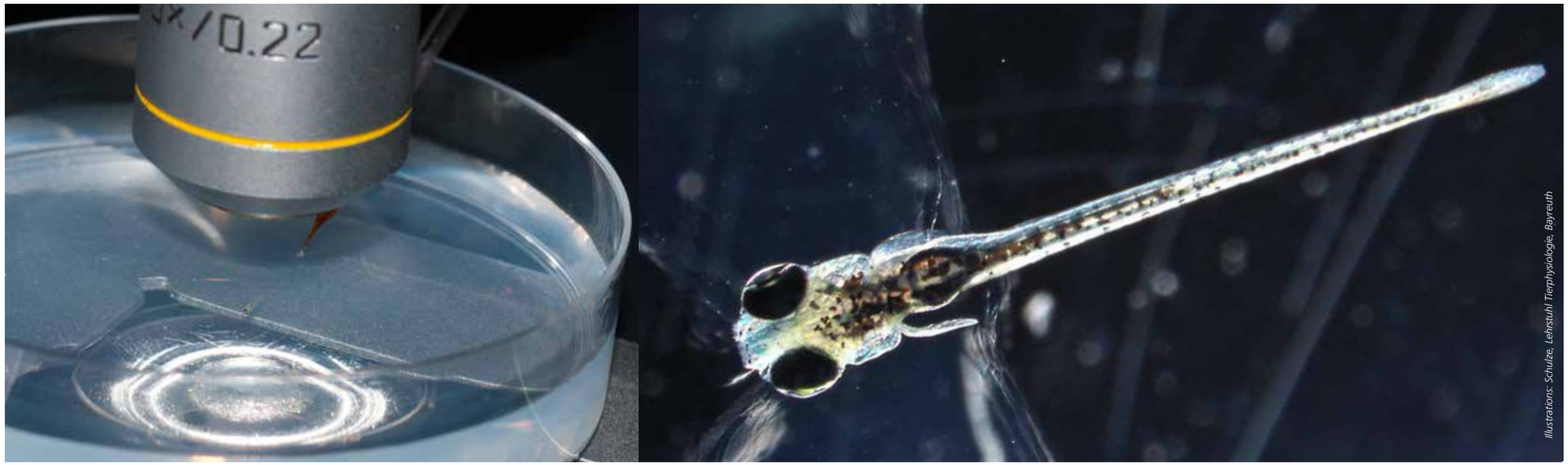
If the fish are confronted with two identical objects that are falling in opposite directions, they chose their start programme for just one of the prey objects. This choice is not at all random: the fish will chose the object that will land the closest to its starting position.

The fascinating thing about the decision made by the fish is that the ecological constraints of the hunt not only require an amazing level of complexity and speed, but that the decision is mediated by a small group of identified neurons that can be identified from one fish to the next. In order to initiate the correct start as soon as possible, the archerfish recruit an interestingly constructed network that other bony fish use to escape from their predators. This network consists of relatively few (a couple of hundred) identified neurons, a situation that is very different from the cerebral cortex, and can be identified individually in each animal.

From the take-off sequence of an archerfish, it can be concluded that the essential aspects of the start decision are mediated by the activity in a network of only six cells. And that's not all: the decision as to whether enough information has been collected to initiate the correct take-off can even be investigated in just two cells, the so-called Mauthner cells. All these cells integrate information from different areas of the brain in their large, very accessible dendrites. They are thus predestined to collate the various pieces of information that are required to make a decision. Finally, a further aspect proved to be unexpectedly useful: this network exists in all bony fish, and in the meantime we have demonstrated with two other species that it can also be recruited to make complex decisions on the basis of environmental rules. Very surprisingly, one of these species is the zebrafish, which has become one of the most revealing model systems for vertebrate brain research.

The Koselleck Project is working parallel with both model systems: archerfish and zebrafish larvae. The aim is to understand which set of cellular network properties is used to represent fundamental environmental rules. The type of representation must on the one hand allow rapid adjustments, and on the other it must guarantee "functional stability", or in order words, it must ensure that the quality of the decision is not affected by fluctuations in external parameters such as temperature or visual contrast. Although these are not relevant to decision-making, they do affect every component in the network.

The DFG's willingness to sponsor high-risk projects has led to extraordinarily good opportunities to study the cellular fundamentals of decision-making and its tuning with constraints and rules. This project has also shown that complex and plastic decisions can indeed be made quickly in relatively small networks. Our goal in coming years is to use the rapid decision-making processes of fish to be able to understand fundamental mechanisms of cognitive behaviour – particularly adaptation to environmental rules – at the cellular and network level. Perhaps this will help to bridge the gap between complex cognitive behaviour on the one hand and the processes occurring at the level of individual cells on the other.



Illustrations: Schulze, Lehrstuhl Tierphysiologie, Bayreuth

A highly detailed and precisely targeted examination under the microscope reveals the secrets of zebrafish larvae. Right: A larva that has been treated with a contrast agent for further experiments.

In-vivo measurements of cells in the decision-making network are essential.

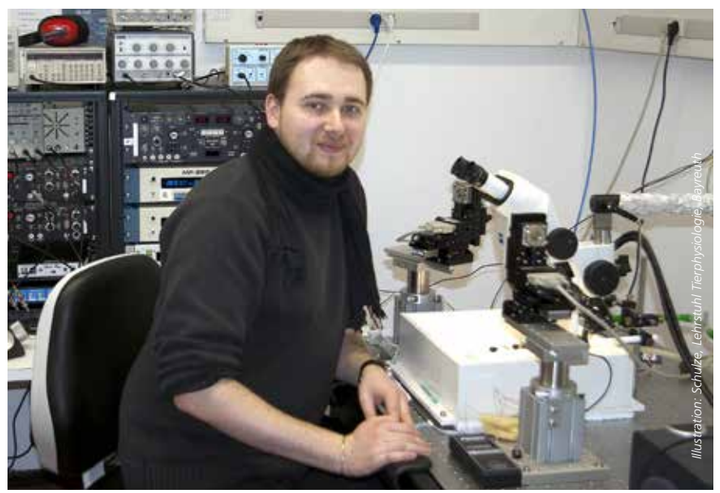


Illustration: Schulze, Lehrstuhl Tierphysiologie, Bayreuth

Prof. Dr. Stefan Schuster
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Henry Greve, Robert Jahns, Jan Raethjen

Faster, More Precise and Visible

Both ECG and EEG often run up against their own limitations. Physicians, electrical engineers and medical scientists are now searching for optimum composite materials to be used in innovative new magnetic field sensors for the diagnosis and treatment of heart and brain diseases.

Expensive, time-consuming and relatively inaccurate: The measurement of electrical phenomena in the human body is still under development. It plays an important role in clinical medicine however. It permits the functional performance of the heart and brain to be determined. In the framework of Collaborative Research Centre (CRC) 855 (speaker Prof. Eckhard Quandt), researchers from Kiel are now developing sensors with which the measurement of heart and brain currents could be faster and more precise in the future. This opens new possibilities for diagnostics and treatment.

In order to diagnose heart problems, up to now, an electrocardiogram (ECG) has been taken in the doctor's office. This involves the application of electrodes to the chest, arms and legs to measure the electrical activity of the heart, which is vital for a healthy heartbeat and the heart's normal function as a pump. Brain currents can also be measured by means of electrodes on the scalp: With a so-called electroencephalogram (EEG), it is possible to gain an insight into the general functioning of the brain or into pathological changes, especially epilepsy.

In both of these measurements, which have become routine procedures, the electrodes are applied directly to the skin with a highly conductive gel, to keep electrical resistances to a minimum. This preparation takes some time – especially for an EEG with many sensors – and can be disagreeable to the patient. Moreover, the electrical signals measured at the surface of the body only give an approximate image of the actual activity in the brain or heart, as they are distorted by the layers of tissue and bone through which they must pass.

As an alternative to the electrical voltage at the surface of the skin, it is also possible to measure the magnetic fields which are generated by the brain or heart. The advantage of this procedure is that these magnetic fields pass through the layers of tissue almost without hindrance, resulting in a virtually undistorted image of the activity going on below the surface. The disadvantage of this approach is that the magnetic fields can be very small and can consequently only be recorded using extremely sensitive sensors and by shielding the normal ambient magnetic fields.

Already today it is possible to measure a magnetoencephalogram (MEG) or magnetcardiodiogram (MCG) in sophisticated shielded rooms, although the sensors required for this presuppose an operating temperature of about minus 200 °C. In order to reach these temperatures, liquid helium or liquid nitrogen is needed for cooling, which means that it is very costly and complicated to make use of the sensors. As a result, this technology is still not commonly used in clinical procedures and is used exclusively for specific scientific problems.

This could change in the near future. The sensors which are now being researched are based on innovative new composite materials which can record the biological magnetic fields of the heart, for example, even at room temperature, without cooling and with an adequate sensitivity. These sensors also have great potential for other application areas, because they do not require any power supply whatsoever. This is enabled by a property, known as magnetoelectricity, which has only received the attention of materials science over the past few years.

In this case, a magnetic field generates an electrical voltage in a material and vice versa. There are only a few natural materials which possess this property, and even these have limited effectiveness when it comes to converting magnetic fields into an electrical voltage. But ever greater magnetoelectricity effects have been attained in recent years. This progress has been achieved by coupling two suitable materials with special individual properties. The interdisciplinary research team is also researching composite materials like this.

The greatest potential for the research work lies in the greater magnetoelectricity effects produced by these combined materi-

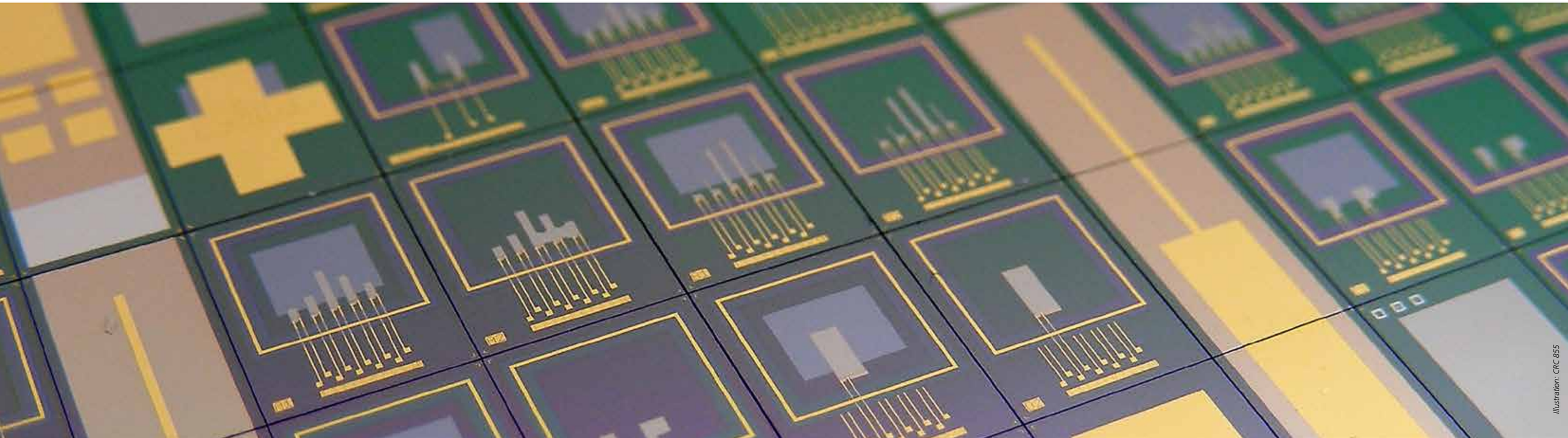


Illustration: CRC 855

als, because these may be several thousand times greater than those of natural materials. When combining two materials, it is important to consider above all the effects at the boundary areas between the two components, as these are critical for the later properties of the composite material.

Apart from researching and optimising such bio-magnetic sensor materials, another goal is to develop a sensor network in order to obtain coherent data sets, which provide information about whether and how sources inside the body produce magnetic fields. This presupposes that the individual sensors do not exceed certain dimensions, so that the highest possible number of sensors can be arranged on a clearly defined surface.

To realise this project, the composite materials are deposited as thin layers on silicon wafers in the clean room of the University of Kiel – a room which is kept as free as possible from all particles and germs. Highly-complicated processes of the kind used to manufacture computer chips enable the micro-structuring of the components.

At the end of the production process, several hundred sensors can be made from one of these wafers and then used in large numbers without skin contact. At present, the smallest "ME sensors" already have a surface of less than a square millimetre. In addition, it is possible to house the actual sensor and the electronics for evaluating the data in a single integrated circuit.

Already in the initial phase, it was possible to significantly increase the sensitivity of the sensors. As a result magnetic fields can currently be measured at room temperature, which are about one million times weaker than the Earth's magnetic field. A sophisticated magnetic shield is still required for this purpose. For the future, the CRC is working on systems which enable an adapted evaluation of the electrical signals and render shielding entirely or at least partially unnecessary. The sensitivity of the sensor system will have to be increased even further for this. That is a research goal which demands a high degree of interdisciplinary teamwork.

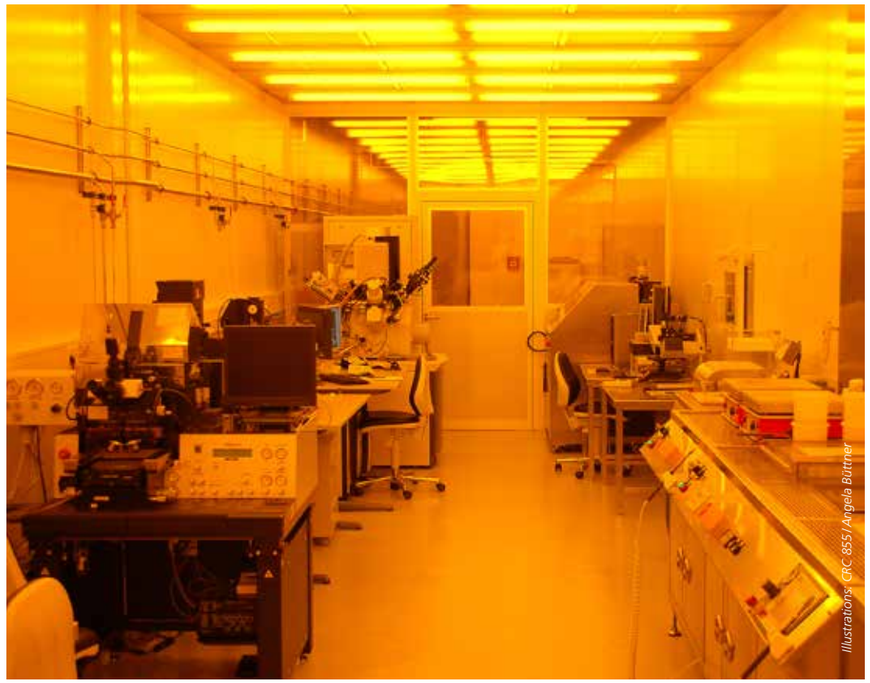
This is why there are physicists, electrical engineers and medical scientists working together in the Kiel research network to develop the new sensor concepts. Physics, for example, researches the effects in the boundary areas on an atomic level, while electrical engineering, on the one hand, works on the measurement technology to achieve the most sensitive possible read-out of the sensors and, on the other hand, examines various signal processing strategies which can be used for noise reduction for instance. Medical science, on its part, develops algorithms, among other things, which make it possible to trace the measured magnetic fields back to the biomagnetic signals.

The idea that magnetoencephalography and magnetocardiography will soon be used in clinical procedures is therefore becoming ever more realistic, and new diagnostic and therapeutic possibilities are opening up. It is already being prepared and tested for the diagnosis and treatment of tremors and epilepsy. An important goal is to discover the components of the network in the brain which are responsible for the trembling or epileptic seizure. For this it is necessary to trace the signals measured at the surface of the body back to the underlying activity in the depths of the brain. Obviously, the success of this process depends on measuring the activity at the surface of the body with as little distortion as possible.

This is where the inestimable value of measuring magnetic fields becomes apparent, as these penetrate through the various layers of tissue without any hindrance. The CRC is doing pioneering work in this field and has developed prototypes of these innovative new sensors which record the currents from heart and brain pacemakers for the treatment of patients with Parkinson's disease and tremors. The exact representation of the current density around pacemakers is a first application of the new sensors. Precise knowledge about the extent of these fields and the associated effects and side-effects could revolutionise the approach to therapy optimisation with heart and brain pacemakers.

If they succeed in operating the new sensors without shielding, this could also open new possibilities for the field of therapy involving brain-computer interfaces. In the case of an incurably paralysed patient, for example, a brain signal could be measured, and the intention to move could then be transmitted via computer to a prosthetic limb or a robot, which would then carry out the appropriate movement. This application possibility is still struggling with the problem that the applied EEG electrodes quickly lose their conductivity. This has prevented long-lasting use of such systems in the everyday life of patients up to now.

The new MEG system developed by the CRC could provide some assistance here. If worn like a normal EEG cap during everyday life, it could ensure consistent measurement quality. This would not only significantly extend the application area of BCI, it would also bring long-term improvement to the diagnosis and treatment of heart and brain diseases.



Illustrations: CRC 855 / Angela Buttner

Above: three researchers in front of a coating facility which is used for making magnetoelectrical, thin films. Right: view into a "clean room".

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The Deutsche Forschungsgemeinschaft

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Impressum

german research is published by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation);
Publisher: WILEY-VCH Verlag GmbH & Co. KGaA, P.O. Box 101161, D-69541 Weinheim;
Annual subscription price: €70.00 (Europe), US $75.00 (all other countries) including postage and handling charges.
Prices are exclusive of VAT and subject to change.
Address of editorial staff: DFG, Press and Public Relations Office, Kennedyallee 40, 53175 Bonn;
postmaster@dfg.de; www.dfg.de

Editor-in-chief: Marco Finetti (responsible for content)
Publishing Executive Editor: Dr. Rembert Unterstell
Copy Editors: Stephanie Henseler, Angela Kügler-Seifert
Translation: SciTech Communications GmbH, Heidelberg; oneword GmbH, Böblingen
Printed by: Bonner Universitäts-Buchdruckerei (BUB);
printed on chlorine-free bleached paper with 50 % recycling fibres.

ISSN 0172-1518

Illustration: DFG / Ausserhofer

Focussing on "the 'new' new": In his first public address as DFG President, Professor Peter Strohschneider underscored the importance and potential of thinking outside the box, to concentrate not only on the "old" new, which targets solutions derived from previously identified problems. Instead, there must be an emphasis on "the extension of the boundaries of the thinkable, on the emphatically innovative, on answers that cannot be predicted from the questions that have already been asked". During the DFG New Year reception in Berlin, the new President, who took up office on 1 January 2013, spoke to approximately 300 guests from the spheres of science and academia, politics and society.