A large 3D visualization of a complex material structure, possibly a lattice or a porous medium, rendered in a blue wireframe mesh. The structure is filled with a color gradient from blue to red, representing stress or strain distribution. The main title 'It's all in the detail' is overlaid on this image.

## It's all in the detail

Computer modelling and virtual testing  
of new materials

### Flight school for trains

Catapult for research

### Test case: Antarctica

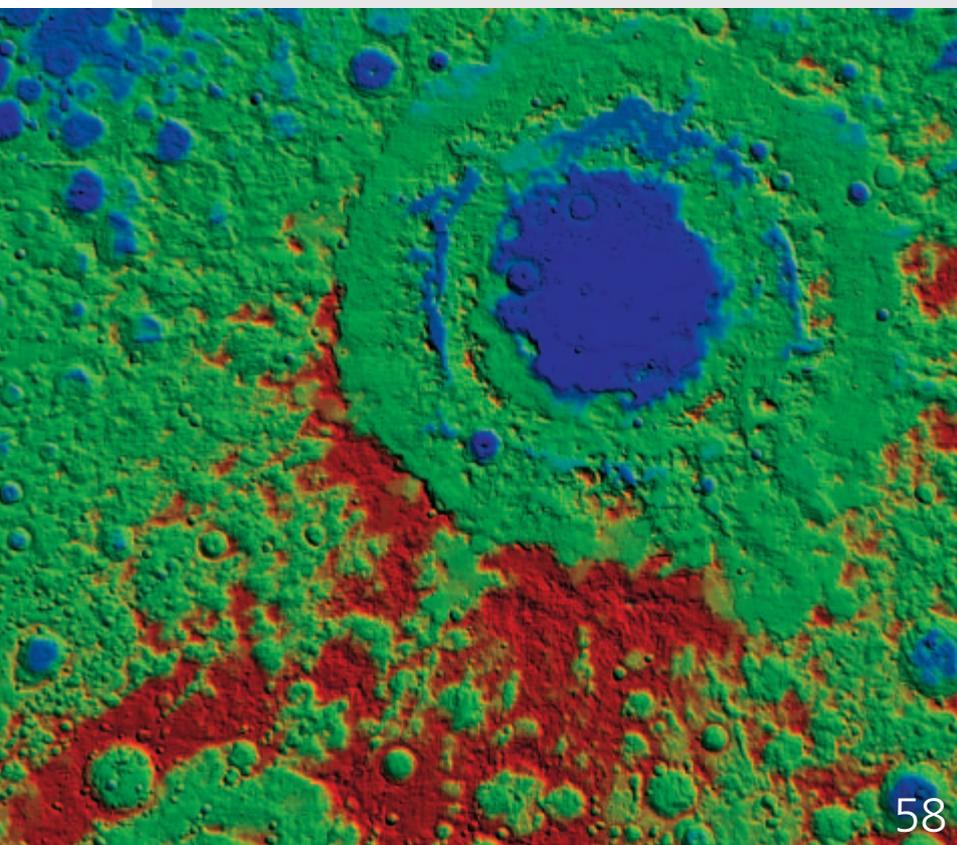
Space medicine on ice

### Interview: Moon mapper

Surveying Earth's companion

### Earth: one of a kind?

Trying to solve the Fermi paradox



## Topography of the Moon

Mare Orientale on the Moon. Our nearest planetary neighbour is located 385,000 kilometres from Earth. That puts it close enough to be observed with the naked eye, and for astronauts to set foot on it. "And yet we still know relatively little about this planetary body," says Jürgen Oberst, someone who knows the Moon like the back of his hand. A geophysicist, he heads the Department of Planetary Geodesy at the Berlin-based DLR Institute of Planetary Research. In an interview with Elisabeth Mittelbach, an Editor in DLR's Corporate Communications Department, he speaks about his involvement in the most recent mission to the Moon, JAXA's Kaguya, as well as NASA's Lunar Reconnaissance Orbiter, which was launched in 2009.

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Dear readers,

It is hard to believe that another year is already drawing to a close. The holiday season is looming – at least for those efficient people who are already planning their gift purchases.

Things remain busy at DLR during these final weeks of 2010. As is so often the case, this is our most eventful time of year. This is despite the fact that, as far as communication is concerned, we have already attended more than 70 events, published over 160 news articles and press releases, and given many visitors to DLR a better understanding of our work. But this list is just the tip of the iceberg; it is almost impossible to put a total number on our missions, research activities, tests, presentations, lectures, official trips, administrative events and so on.

There is still plenty more on our agenda between now and Christmas. This period includes the Annual General Meeting, one of the most important events in DLR's calendar. The highest body in DLR, the DLR Senate, meets twice a year. It consists of 33 members representing science, the economy and industry, as well as representatives from national institutions. Traditionally the 'Autumn Senate' is held in late November under the leadership of the Chairman – currently Jochen Homann, State Secretary in the German Federal Ministry of Economics and Technology – and has the task of reviewing the past year. Much-awaited staffing decisions are taken and the direction for the coming year is set out.

The evening event following the meeting, which takes place at a different DLR site and therefore in a different German state each year, is an important tradition. This means that the home states of the various DLR sites become a focus of attention in turn and the different sites themselves are acknowledged. A review of the year in film format – now an essential part of the event – will once again showcase how diverse DLR is, how motivated its staff members are and, above all, the excellent research work they are carrying out. You too can watch the review of 2010 by visiting [www.DLR.de](http://www.DLR.de); or simply browse through this latest edition of the DLR Magazine and read about the highlights of our Year of Science 2010.

I hope you enjoy reading the magazine and wish you a peaceful holiday season and much success in 2011.

Sabine Göge  
Head of DLR Corporate Communications



### Flight school for trains

DLR facility uses a catapult to accelerate train models for high-speed testing 40



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# Perspective



## HALO spreads its wings

Another milestone has been reached in preparing DLR's new High-altitude and long-range research aircraft, HALO, for routine scientific use. HALO flew the first mission during which it carried scientific instruments in late October. On board were a lidar and a mass spectrometer from the DLR Institute of Atmospheric Physics, radiation sensors from the Jülich research centre and the Universities of Mainz and Leipzig, and an air sampler from the University of Wuppertal. These instruments have subsequently been used on several further test flights. Prior to these scientific test flights, a complex data acquisition system and specially-developed sensors for measuring meteorological parameters were thoroughly tested and calibrated during an extensive flight testing programme. Once outstanding approvals are completed, HALO will serve German and international researchers and, thanks to its long range and high altitude capabilities, will deliver eagerly anticipated results in both atmospheric research and Earth observation.



ommunications  
Maritime security

Positioning

Position measurement

Flooding

Position measurement

Disaster management



Information

Airport security

Hazard prevention

Communications

Laser

Maritime security

# Researching security

By **Johann-Dietrich Wörner**,  
Chairman of the Executive Board



**Johann-Dietrich Wörner**,  
Chairman of the Executive Board

Security is one of life's basic necessities. The term means a condition or situation that is free of unacceptable risks. In technical terms, risk is the multiplicative product of the probability of an event and the severity of the damage it causes. In daily usage, the meaning of security is reduced to the opposite of risk, or rather, residual risk. Buildings, procedures, pharmaceuticals, events and entire social systems – they must all be safe. The concept of security has a special meaning for each individual in society. Although we may enjoy taking risks repeatedly, even intensifying them for the kick they give us during our leisure activities, we want society to protect us from risks and keep us secure in everyday life. Security is a need with special features, a condition that is not self-evident, and the need for which is felt only when it is absent. It is something that has to be studied and worked towards.

DLR is very closely engaged with all issues of security, both in the direct, technical sense and in society at large. Our research into security includes, on the one hand, defence research: providing the German Federal Ministry of Defence with our assessment and consulting expertise in the area of militarily-relevant technologies. On the other hand, civil security research projects are fundamental to our work: supporting technologies, systems, concepts and expertise as well as the associated capabilities in the areas of active and passive protection. DLR's civil security research also includes the field of safety, when a failure, whether human or technical, has occurred, or a natural event has had devastating consequences.

DLR established its Security research programme in spring 2010. A Programme Coordinator has been appointed to steer and coordinate security-related activities within DLR. Working with Members of the Executive Board and Programme Directors for the areas of Aeronautics, Space, Energy and Transport research, the Coordinator harmonises these activities and as the primary contact for both internal and external partners, represents the interests of Security research. Within DLR itself, special weight is accorded to the initiation of new civil security research projects in consultation with federal, regional, industrial and scientific partners.

The foundations for performing security research at DLR are excellent. Our expertise and capabilities go far beyond pure technology development to include secure communications, navigation and remote sensing. Especially in the area of security, it is important that a range of disciplines be coordinated systematically in order to provide clear, unified data analyses, thereby enabling reliable situation evaluations and recommendations for action. DLR has recently provided active assistance after many catastrophes around the world, from the earthquake in Haiti to the forest fires in Russia and the floods in Pakistan, and has developed information products from raw data that have been – and continue to be – of enormous value to humanitarian agencies in the field. Multidisciplinary concepts, such as airport security, aimed at making critical infrastructure safe, are also areas of active research in addition to themes such as maritime security.

We at DLR will continue to actively pursue all aspects of security research, so as to deploy the full range of our expertise for the benefit of society. Research is indispensable to security. ●

# On guard against the shifting sea

Indonesia is closer to Oberpfaffenhofen than you might think. At least in the newly-opened Service Lab at DLR's Earth Observation Center, where information from the Center for Satellite Based Crisis Information, the World Data Center for Remote Sensing of the Atmosphere and the Reference Platform for Environmental and Crisis Information Systems all come together. "From here, we can track on our monitors how our tsunami early warning system in Jakarta is behaving," says Ulrich Raape from DLR's German Remote Sensing Data Center.

## Tests at DLR's Earth Observation Center Service Lab deliver an improved tsunami detection system

By **Manuela Braun**

On their monitors, the DLR researchers are testing how their decision support system for use in Indonesia can be improved further. "We have a copy of the software, which we developed, running here in the Service Lab," says project leader Raape. The software is designed to integrate data from the early warning centre in Jakarta in real time, around the clock, and help to judge whether a tsunami is building in the Indian Ocean following a suboceanic earthquake. The island nation has very limited possibilities for advance warning in order to organise evacuations, so it has to react to signs of trouble very quickly. The results of the tests in Oberpfaffenhofen will be transferred to Indonesia and are intended to ensure that the country and its people are better prepared for future tsunamis. "All information systems which are developed at the German Remote Sensing Data Center or at DLR's Remote Sensing Technology Institute can be simulated and tested in pre-operational deployment here at the Service Lab."

The Oberpfaffenhofen facility, which has many departments working closely with one another, is ideal for creating synergies. "Interaction between scientists working in different areas is possible in a special way here," says Stefan Dech, Director of the German Remote Sensing Data Center, which oversees the Earth Observation Center in collaboration with the Remote Sensing Technology Institute. "And the Service Lab is the premier data source for scientists and clients in the area of remote sensing services for management of the planet." Up to 30 scientists are working in the Service Lab at any one time, their constant close contact allowing the sharing of progress, results and the latest developments. "It is especially encouraging that scientists from very different disciplines can exchange ideas. That inspires us and creates the potential for new ideas." Atmospheric scientists, for instance, are located next door to early warning system developers and specialists in regional crisis data processing. The rooms of the Service Lab are never empty, and the new Center for Satellite Based Crisis Information is generally staffed around the clock, providing satellite information about natural catastrophes and humanitarian crises. Among the most recent projects in the Service Lab, along with the

tsunami early warning system, are the mapping of flooded areas in Pakistan, in Senegal along the River Niger, and in Slovenia. And the World Data Centre for Remote Sensing of the Atmosphere has recently completed a project to provide real-time predictions of air quality in Bavaria. "The idea behind the Service Lab is to deploy the results of our research and make them directly applicable to urgent problems of our changing environment and natural catastrophes. These are real-life applications put to the service of mankind," says Dech.

For Indonesia, the results are already clear – the decision support system software will be deployed in the Jakarta early warning centre to pull together the processed data from seismometers, buoys, pressure sensors and tide gauges and combine it with a database of simulation scenarios. "And from all these bits and pieces it can build a big picture, evaluate the scenario, and support operators in their decision-making processes in the control room," explains project leader Raape. "What's the risk level? Which warning level should be set for each area? The system gives real-time recommendations in answer to these questions." ●

### About the author:

Manuela Braun is an Editor in DLR's Corporate Communications Department.

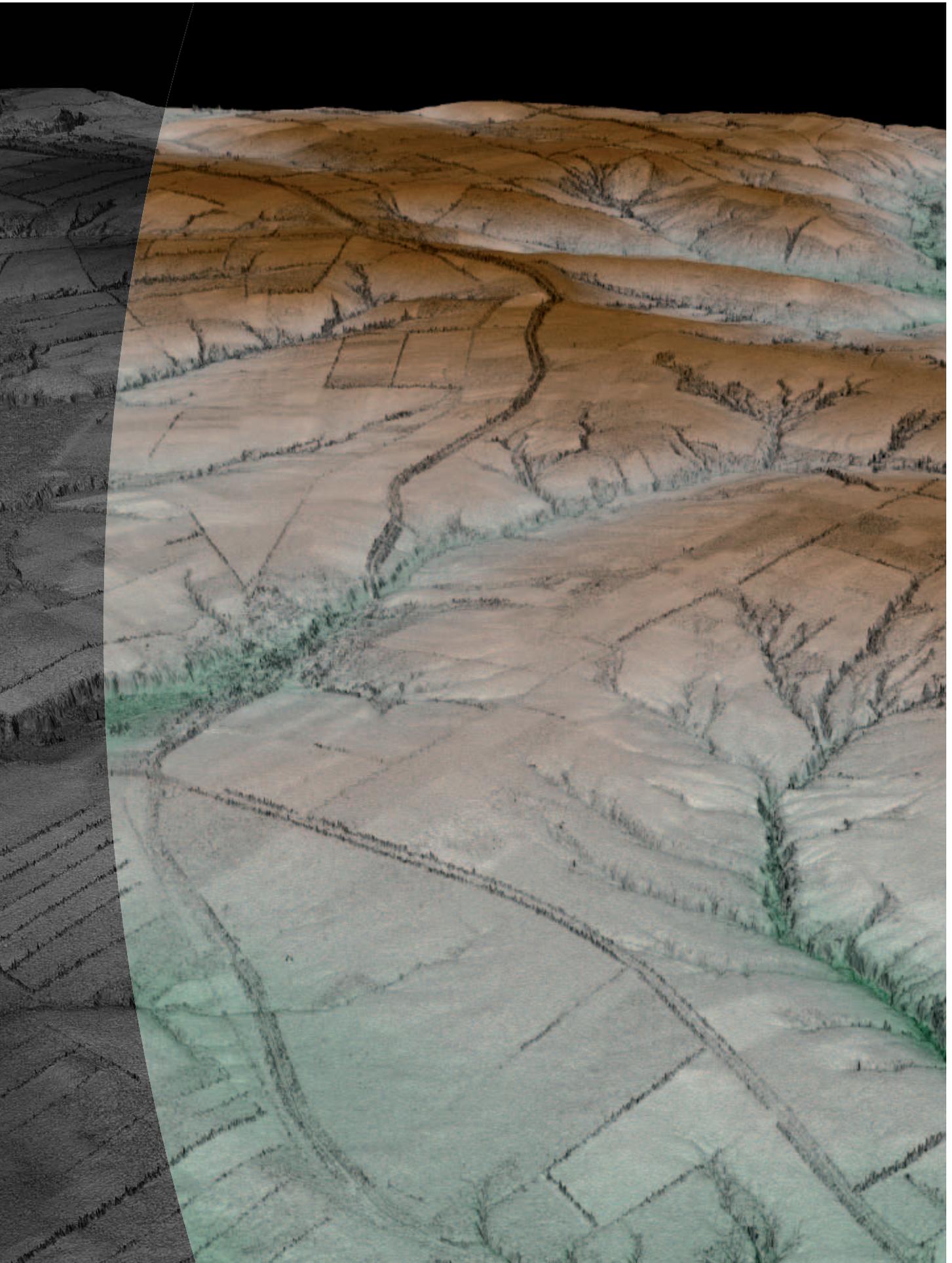
### More information:

Earth Observation Center  
[www.dlr.de/caf/en](http://www.dlr.de/caf/en)

Center for Satellite Based Crisis Information  
[www.zki.dlr.de/en](http://www.zki.dlr.de/en)

World Data Center for Remote Sensing of the Atmosphere  
<http://wdc.dlr.de>





# Twin satellites look into the third dimension

Two nearly identical X-band radar satellites are circling Earth in close formation. They are preparing to gather the data needed for a new three-dimensional map of the planet's surface – a digital elevation model which will be unprecedented in both its accuracy and uniform nature.

## What makes the formation flight of TerraSAR-X and TanDEM-X unique?

Interview by Manuela Braun

TanDEM-X and TerraSAR-X are flying at 27,000 kilometres an hour, 514 kilometres overhead, each imaging Earth's surface with their radar. After the launch of TanDEM-X on 21 June 2010 from Baikonur in the Kazakh steppe, they were roughly 16,000 kilometres from one another – about half an orbit. The semi-major axis of TanDEM-X's orbit was set to be 4.6 kilometres lower than that of its twin, giving it a higher orbital velocity so it could 'catch up'. From 12-21 July, a sequence of orbital manoeuvres brought the two satellites into a formation where they were flying one behind the other, just 20 kilometres apart. During this time, the radar on TanDEM-X was tested and calibrated, and the satellites worked together to acquire their first, experimental three-dimensional images. Since October, they have been flying in formation, even closer to one another. This is when the mission really began for the TanDEM-X team.

Manuela Braun, Editor in DLR's Corporate Communications Department, spoke to Harald Hofmann, Mission Operations Director at the German Space Operations Center in Oberpfaffenhofen.

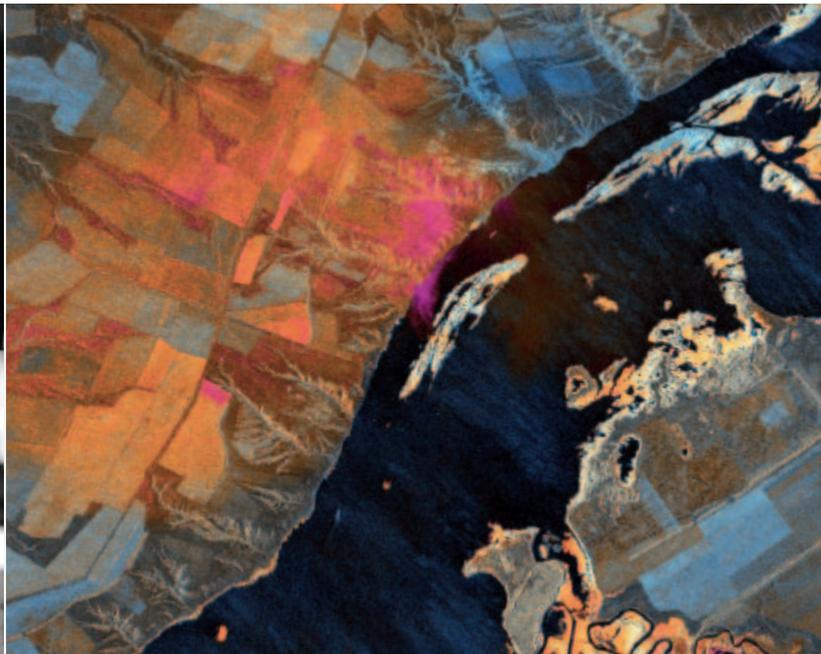
### How close did the two satellites come in October?

We brought TanDEM-X as close as 200 metres to TerraSAR-X. The satellites are flying in a 'helix formation', which means that TerraSAR-X follows its normal orbit, while TanDEM-X loops around this flight path, like a strand of DNA. The distance between the two satellites in the direction of flight varies between zero and one kilometre, while vertically they will be a minimum of 200 metres apart.

This TanDEM-X elevation model, coloured with shades conventionally used in atlases, shows the region around Kalach on Don in southern Russia. The elevation in this model is greatly exaggerated – the landscape has a height range of about 200 metres. The high resolution of the data in the image reveals not only valleys and plateaux, but also roads and field boundaries



Harald Hofmann, responsible for mission control



A successful test: TerraSAR-X imaged these fields in 2007 and TanDEM-X has acquired data from the same location to compare their performance

## About the mission

As they orbit Earth, the nearly-identical radar satellites TanDEM-X and TerraSAR-X will be collecting data for a homogeneous, three-dimensional elevation model of the entire surface of our planet, unaffected by weather conditions or the availability of sunlight. TerraSAR-X has been recording data from an altitude of 514 kilometres since 2007, while TanDEM-X was launched on 21 June this year. Since October, the satellite duo has been flying in a helix formation while using their radar instruments to scan the 150 million square kilometres of Earth's surface from various points of view. In this manner, the twin satellites can, for example, measure the extent of the Antarctic ice cap, supply data on areas at risk of flooding, observe water currents, or view moving objects and measure their speed.

### A satellite mission consists of multiple phases. What phase is TanDEM-X in now?

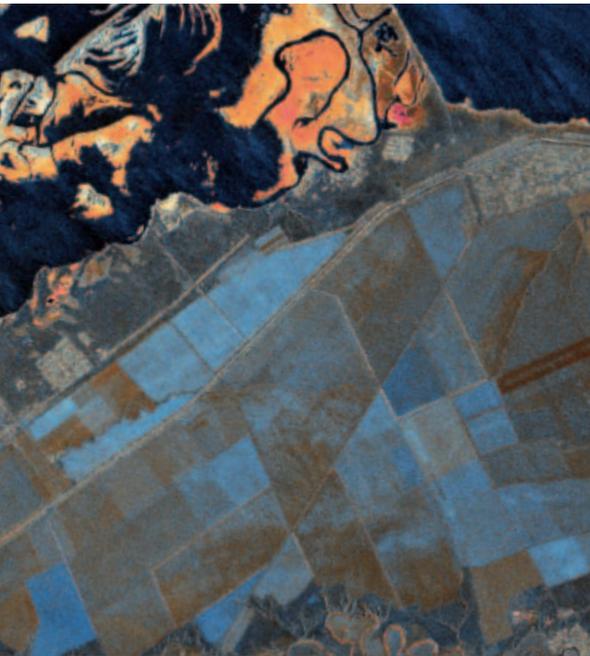
Until October, TanDEM-X was in its monostatic commissioning phase. This means that the satellite was being tested on its own, without the involvement of TerraSAR-X. These tests – the same ones that we carried out on TerraSAR-X – were completed successfully. Now, the TanDEM-X radar is fully calibrated to give it the same performance as its counterpart, so it can acquire images in all three modes of operation in precisely the same way as TerraSAR-X.

We are now in the bistatic commissioning phase, which will last until the end of this year; routine operations will commence early next year. During the course of the mission, we will change the helix formation several times, which means that we will position the satellites at different distances from one another to achieve different viewing angles. Specific areas, such as steep mountains and canyons, need to be imaged up to four times. Overall, we need about two and a half years to capture all the data we need. The complete three-dimensional digital elevation model of Earth should be ready around four years after launch.

### What can the TanDEM-X radar do and what new knowledge can be obtained with this type of formation flight?

The radar can acquire images of Earth's surface in three modes: spotlight, scansar and stripmap. The differences are in the resolution and the size: spotlight, as the name suggests, produces very small images. The frame usually has an image size of 10 by 10 kilometres and resolution down to one metre. Scansar images, on the other hand, cover an area 100 kilometres wide but have a resolution of only 18 metres. Stripmap images are around 30 kilometres across, with a resolution of about three metres.

Using two satellites in close formation that view the Earth from different angles enables the generation of the digital elevation model, which is the primary goal of the TanDEM-X mission. It



The control room during the TanDEM-X launch

also makes other new techniques possible, such as measurement of the speed of ground targets moving in any direction.

#### Is there a precedent for satellites flying so close together?

In principle yes, although only experimentally; for example, with the US Orbital Express or the Swedish PRISMA missions. But employing such a close formation operationally and for a long period of time is what makes the TanDEM-X project the first of its kind worldwide. At the German Space Operations Center, we have gained experience in formation flight through our involvement with the GRACE project, although the distance between satellites in that case is more than 200 kilometres.

#### How did TanDEM-X reach its new flight path?

This is where our Flight Dynamics team comes in. They generate commands based on flight procedures that are prepared in advance, such as activating the thrusters for two minutes to carry out a manoeuvre. We send this command up to the satellite, which has GPS receivers on board and we can use the GPS data to check that the manoeuvre was executed properly.

Of course, there is a chance that the satellite behaves unexpectedly. For example, the thrusters may produce a couple of percent more or less thrust than expected. To prevent this from happening, we have been analysing every TanDEM-X manoeuvre over the past few months very closely.

#### TerraSAR-X and TanDEM-X are almost identical in construction, but doesn't TanDEM-X have an additional cold gas propulsion system? ...

Yes, that has been added for formation flying. Both satellites have hydrazine thrusters, which supply a comparatively large amount of force. This system is used for large orbital manoeuvres. However, TanDEM-X is flying along a very narrow helical path at a distance of only 200 metres from TerraSAR-X.

TanDEM-X uses the cold gas system for this, with nitrogen as the propellant. Each of the nozzles produces a thrust of only 0.04 newtons, so we can control the propulsion much more accurately.

#### How do you get the satellites to safely fly so close to each other?

From an orbital perspective, it's really not that difficult. The helical formation is so sophisticated that the satellites fly in what is known as 'passive stability' with respect to one another. This means that they cannot collide without an external influence such as gravity or use of the propulsion systems. Perturbations cause this passive stability to last for only around two weeks, after which orbit maintenance has to be performed. However, this setup is more than adequate for operating the satellites. The primary challenge lies in planning the operations such that we do not compromise the formation unnecessarily or damage the satellites in some way.

#### What precautions have you had to take to achieve this?

Oh, many. Essentially, we have introduced extra programs and functions throughout the whole ground system and on the satellites themselves. One example is the exclusion zone check: when both satellites are flying in close formation, we must prevent them from illuminating one another with their radar transmitters, as this could damage the electronics. Therefore, there are precautions that prevent radar activity from taking place when one satellite is flying through the other's field of view. Only one of the radars is allowed to transmit at such times.

#### How precisely can the satellite's paths be determined and controlled?

For formation flying it is sufficient for the Flight Dynamics team to set up the formation with an accuracy of 20 metres. Then the geometry of the formation has to comply with the requirements for the instruments when they are looking at Earth stereoscopically. The strictest requirement comes from processing

the data for the digital elevation model. When the data is processed at the German Remote Sensing Data Center, the position of the two satellites relative to one another must be known down to the millimetre. We have created a special data product to achieve this, called the precise baseline.

#### Who is in the TanDEM-X mission team?

Four Institutes are involved at Oberpfaffenhofen: the Institute of Microwaves and Radar Systems is responsible for operating and calibrating the radar instruments and overall planning of acquisitions for the digital elevation model. The radar data is received, processed and archived at the German Remote Sensing Data Center and the Institute of Remote Sensing Methodology. Here at the German Space Operations Center there are four departments working on the mission: Flight Dynamics, the Ground Data System (responsible for communication with the tracking stations), Mission Planning (which generates the commands for the radar data we require), and the Flight Operations System (the control centre where the engineers responsible for the various satellite subsystems work).

#### That's a large team of people...

Yes, there are some 50 people in the operations team alone. Some work only on TanDEM-X, while others work on several projects. The busiest period was around the time of the launch in June. Normally things quieten down after the launch, but with TanDEM-X we were busy again in October, monitoring the satellites as they neared close formation flight. We worked in shifts in the control room again for two days.

#### When did you obtain the first three-dimensional image of Earth?

Even when the satellites were flying 20 kilometres apart, which represents a separation of three seconds, we were able to control them and steer their radar beams to capture the first test images. We started taking normal three-dimensional images as soon as they were flying in close formation.

#### How long does it take from sending a command to receiving an image?

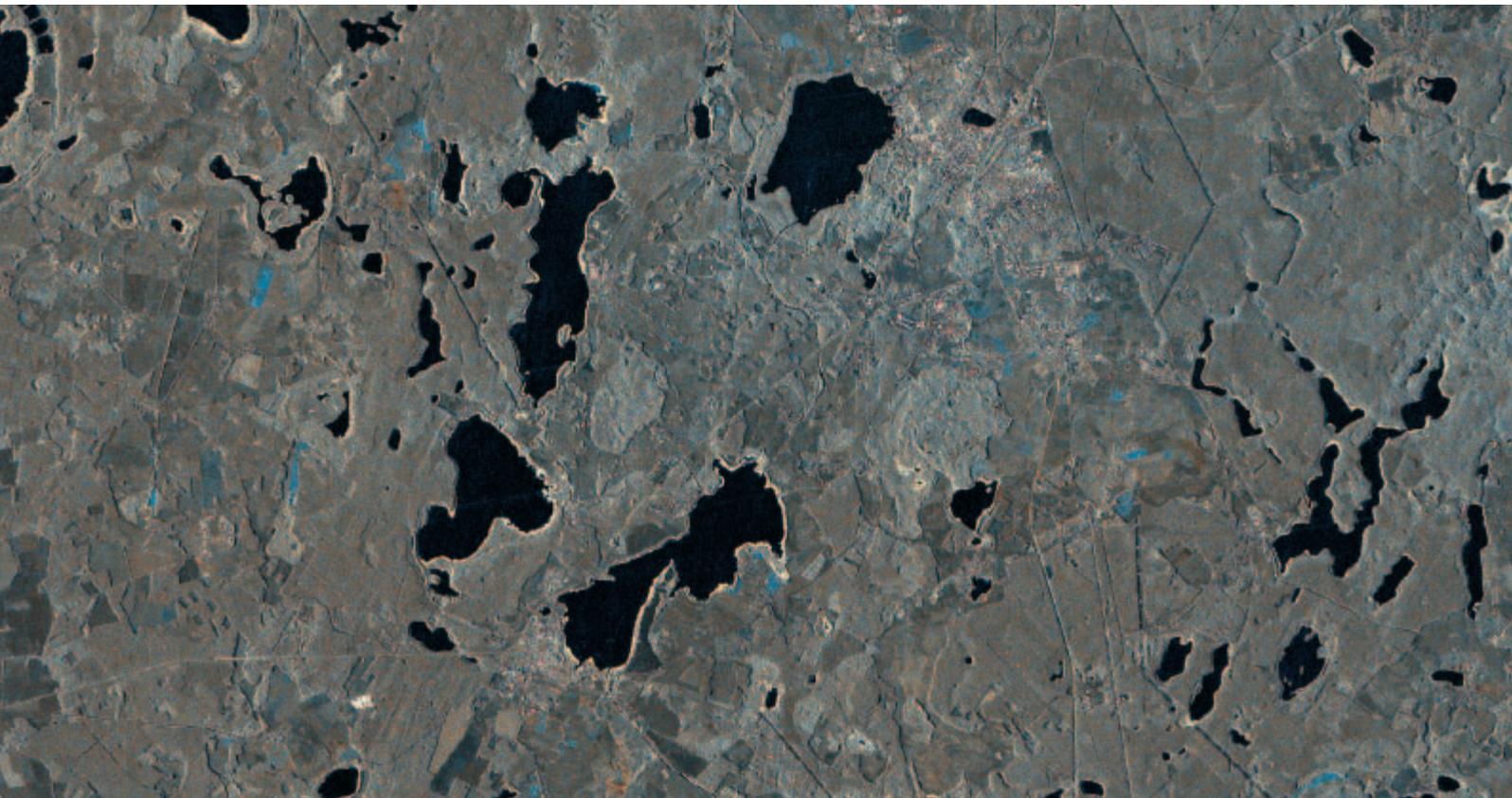
That's not easy to answer. Mission planning takes place twice a day and high priority orders can come in at short notice – up to six hours before a planning run. Then the commands for controlling the radar instruments are generated. Our principal uplink stations in Weilheim and Neustrelitz send commands to the satellites every morning and evening.

The timing of the image acquisition depends on when the satellites are flying over the area of interest. TerraSAR-X and TanDEM-X fly over the same points on Earth every 11 days. But we can turn the satellites or steer their antennas to reduce this to less than three days. Finally, we need a tracking station to receive and process the data. When it all comes together nicely, the process can be completed within a day, even six or seven hours under ideal circumstances. ●

#### More information:

[www.DLR.de/earthobservation](http://www.DLR.de/earthobservation)

[www.DLR.de/blogs/en/tandem-x](http://www.DLR.de/blogs/en/tandem-x)



The area around the DLR tracking station in Neustrelitz as seen by TanDEM-X's radar



## The mission in figures

- » Global coverage of the entire land surface of Earth will require **10,000 synchronous radar images, acquired** using both satellites. It will take 27 radar passes to cover Germany and one year to acquire the first global data set. Two acquisition cycles will be required to generate a highly accurate elevation model of Earth
- » The anticipated volume of data is around **1.5 petabytes (1 petabyte = 1,000,000 gigabytes)**. This corresponds to a storage capacity of almost **200,000 DVDs**. The shortest acquisition time for individual radar images using both satellites is five seconds; the longest is 400 seconds. The satellites synchronise their internal clocks 10 times per second when acquiring a radar image together
- » The mission planning system team generates command files for each of the two satellites at least twice a day. A command file can contain up to **1500 individual commands**. These commands arise from the modelling of up to 10,000 individual activities per day, with 300 resources and 280 constraints per activity. Over the lifetime of the mission (around three years), the mission planning system will generate a total of up to 6,500,000 individual commands, which consist of **10 million individual activities** and **a hundred million resource update steps**
- » Calibrating the satellites required scientists working in **86 locations**. The result was 40 active and passive calibration targets
- » TanDEM-X circled the Earth 385 times during the period between its launch on 21 June 2010 and 16 July. The satellite, which is travelling at around seven kilometres per second, covered **15.4 million kilometres in 25 days**
- » During the critical launch and early orbit phase following liftoff, TanDEM-X needed **66 kilowatt-hours** of energy



The 13-metre antenna receives data from both of DLR's radar satellites, TanDEM-X and TerraSAR-X. The location of the ground station in northern Canada guarantees the best possible data reception conditions

## DLR satellite receiving station on duty in Canada

**DLR has commissioned a satellite data receiving station at Inuvik, the northernmost town in Canada that is accessible by road all year round. Its main task is to receive data from Germany's TanDEM-X satellite mission. The 13-metre antenna receives data for use not only by the partner countries, Germany and Canada, but also for researchers from around the world.**

DLR has been collaborating with the Canadian Space Agency and the Canada Centre for Remote Sensing for many years. The location of the station, north of the Arctic Circle in western Canada, gives the station numerous line-of-sight contacts per day with all Earth observation satellites in polar orbit, and seamless data reception. This is crucial for TanDEM-X, which launched on 21 June 2010. The mission's three-dimensional measurements of the Earth's surface yield up to 350 gigabytes of data daily, which must be transmitted from the storage systems on the TerraSAR-X and TanDEM-X satellites to the ground station. To transmit such a large amount of data, numerous line of sight contacts are required, with a total connection duration of more than two and a half hours.

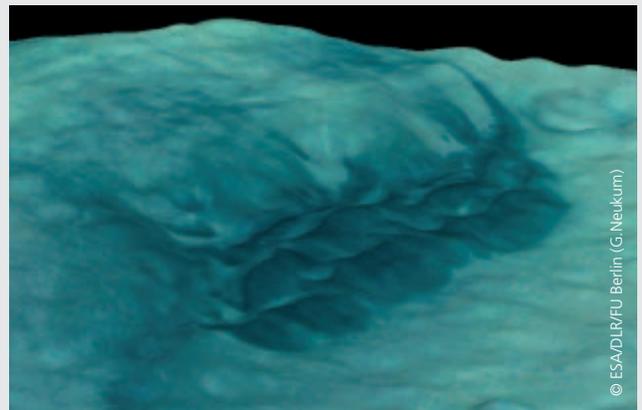
DLR has already pioneered the building and operation of Antarctic satellite ground stations, with a near-polar ground station on the O'Higgins peninsula in Antarctica. Thanks to its partnership with the Swedish Space Corporation, DLR also has access to the Kiruna ground station in northern Sweden. The new station in Canada further expands DLR's worldwide network of ground stations, operated by the German Remote Sensing Data Center located at DLR's site in Oberpfaffenhofen.

[www.DLR.de/blogs/en/tandem-x](http://www.DLR.de/blogs/en/tandem-x)  
[www.asc-csa.gc.ca/eng](http://www.asc-csa.gc.ca/eng)

## Making a match between Mars and Hawaii

Dark dunes seen on Mars are similar to sand dunes on Earth. Comparing mineral samples from the Ka'u desert on Hawaii and spectral data from dunes on Mars has shown this; the dunes have a similar volcanic origin, but they differ in how they weather. Dunes on Earth absorb water from rainstorms. Due to the absence of rain, chemical weathering does not occur on Mars. DLR planetary researchers have concluded that the dark dunes on Mars were created after water disappeared from the planet's surface; that is, less than 100 million years ago.

[www.DLR.de/pf/en](http://www.DLR.de/pf/en)



Dark dunes on the Thaumasia region on Mars

© ESA/DLR/FU Berlin (G. Neukum)

## Mango and Tango orbit Earth in precise formation



Tango, imaged from Mango with its digital video system

© Swedish Space Corporation (SSC)

The Swedish PRISMA satellite mission has entered its second phase – the Mango and Tango satellite duo have embarked on their formation flight, marking the start of a DLR experiment based on an innovative navigation system. Developed by DLR's German Space Operations Center in Oberpfaffenhofen, this system contains a GPS receiver that is barely the size of a credit card. The entire guidance, navigation and control system was also provided by the Center. Data from the receiver on Tango is sent to the main satellite, Mango. By comparing it with data from Mango's receiver, the distance between the satellites can be determined to an accuracy of 10 centimetres in real time. Mango can use this information to control its path in relation to Tango with absolute precision and autonomously follow a predetermined flight path.

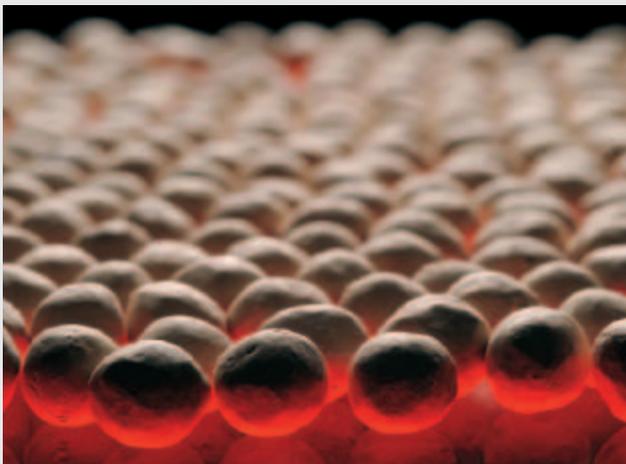
The objective of PRISMA is to demonstrate autonomous onboard control of satellite formations and rendezvous with other spacecraft. The two satellites Mango and Tango were launched on 15 June 2010 and were initially mated together. After successful separation, they are orbiting Earth close to one another, moving further apart and then closer together. This achievement gives the science team the world's first operational test bed to trial different processes in autonomous formation flying and satellite rendezvous.

The next step is for the German Space Operations Center to take over operational control of the satellites – planned for spring 2011. Then, DLR will be engaged in key operations for both PRISMA's space and ground segments. A long-term objective of this involvement is to prepare and test the rendezvous and docking manoeuvres required for on-orbit servicing missions or for more general space robotics.

[www.DLR.de/RB/en](http://www.DLR.de/RB/en)  
[www.prismasatellites.se](http://www.prismasatellites.se)

## Research grant for solar energy storage

As part of a research initiative by energy provider E.ON, DLR has been awarded a project grant of one million Euro to develop a new heat storage system for solar-thermal power plants. Energy from the Sun will be stored as heat in low-cost solid materials. The objective of the project is to develop a technically and economically attractive solution for commercial use in solar power plants. The storage system is being designed with a capacity of 500 kilowatt-hours and will operate at temperatures of up to 400 degrees Celsius. DLR's research team will install the resulting design at a pilot plant in 2013.



Various materials, including stone, concrete and even cooking salt, can be used in solid storage systems for solar-thermal power plants. DLR is studying appropriate concepts

Solar-thermal power plants need energy storage to provide electrical energy at night and at times when the amount of available sunlight is low, so as to extend the hours of operation of the generator turbines. It is already technically feasible to install energy stores, but current systems based on molten salt require a great deal of investment by the power plant operators. DLR is therefore investigating the use of low-cost solid materials such as stone or concrete.

[www.DLR.de/TT/en](http://www.DLR.de/TT/en)



DLR researcher  
**Wolf-Dieter  
 Steinmann** receives  
 the E.ON Research  
 Award

© E.ON AG

## Nose job for the train of the future

**A new design for the nose of the power car of multiple-unit trains makes them lighter and saves energy while also being safer in a collision. This innovation is part of DLR's research and development work for the 'Next Generation Train'.**

In a DLR webcast produced at the InnoTrans 2010 international rail transport trade fair, Next Generation Train Project Manager Joachim Winter demonstrates how this slimmed-down train nose reacts in a collision. Previous multiple-unit trains have been fitted with covered impact absorbers to dissipate the energy from a collision. DLR's solution, presented at the trade fair, features a glass-fibre reinforced power car nose that acts as the impact absorber and prevents damage to the vehicle structure behind it. Repairs are carried out by simply replacing the nose of the power car. This innovation was demonstrated live to visitors to the DLR stand using a model.

[www.DLR.de/ngt-webcast-en](http://www.DLR.de/ngt-webcast-en)  
[www.DLR.de/FK/en](http://www.DLR.de/FK/en)



At the DLR stand at InnoTrans, DLR researchers showed a sample of railway transport research topics, of which the 'Next Generation Train' project is a focal point. DLR also presented pending questions on rail traffic management and reliable train tracking

## Rosetta's lander goes LEGO

**A LEGO model of the European Rosetta spacecraft's lander will become part of a collection of educational materials based on the comet chaser mission. The project is funded by DLR, the European Space Agency and the LEGO Group. The LEGO Lander was first presented in autumn 2010 at the European Planetary Science Congress, and was tried out by engineering students from the University of Rome and art students from the European Institute of Design.**

By reproducing some of the functionalities of the lander using LEGO MINDSTORMS, the students were able to learn all about the mission to Comet Churyumov-Gerasimenko. At the same time, they studied the topic of cometary science from an artistic viewpoint.



Engineering students from the University of Rome testing the model of Rosetta's lander Philae. Its form is already visible.

Creating a replica of the lander was no easy task. Philae has 'ice screws' on its legs, which will bore into the surface of the comet using energy harnessed during the landing. The lander is also fitted with a harpoon to anchor it to the surface. As the screws and harpoon do their job, the lander will be held in position by the thrust from a small engine mounted on its upper surface. Many of these features can be reproduced using the model and a standard personal computer. For the students, the model was a chance to better understand the challenges tackled by space engineers and to develop their own design solutions. Soon, the material will be used in schools and universities across Europe. An accompanying 20-minute film, 'Rosetta's Comet Touchdown', explains the scientific and technical aspects of the mission. The film is available for viewing on the DLR website:

[www.DLR.de/en/philaegoeslego](http://www.DLR.de/en/philaegoeslego)

Related videos:

[www.vimeo.com/channels/rosettascomettouchdown](http://www.vimeo.com/channels/rosettascomettouchdown)



Dark absorber tubes in the receiver being checked

## The SOLHYCO hybrid power station goes online in Spain

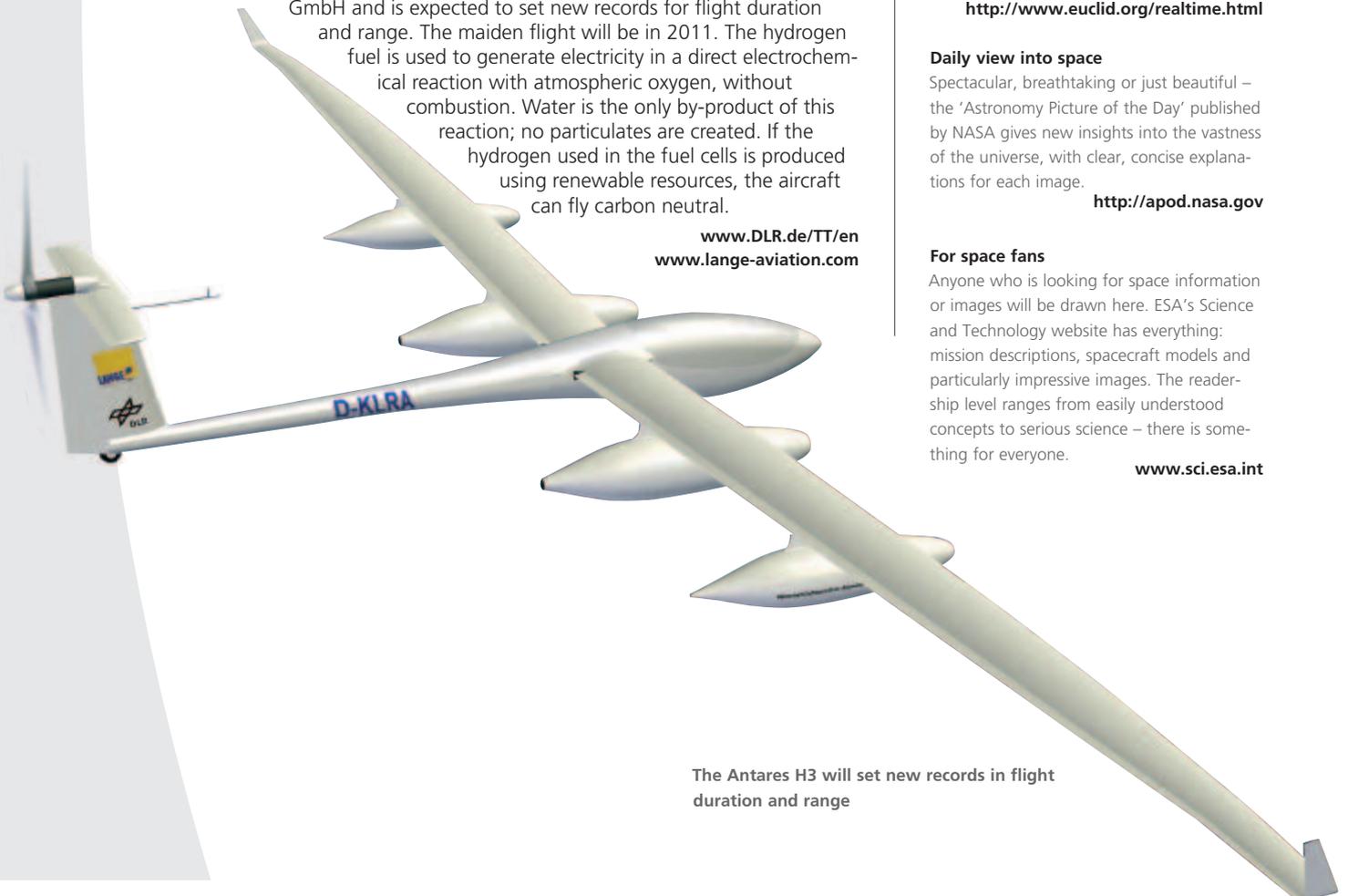
At Almería, in southern Spain, DLR energy researchers working with partners from Europe, Brazil and Mexico have commissioned the SOLHYCO hybrid solar power station. So long as the Sun shines, the station is powered by sunlight, but when it is cloudy or at night, it is fuelled with diesel. If it were to be powered with biofuels, it would be able to run round the clock on renewable resources. The small power station is able to provide electricity for around 50 households. DLR plans to develop the hybrid power station concept further; the next step is a five-megawatt power station.

[www.DLR.de/TT/en](http://www.DLR.de/TT/en)

## Second-generation fuel-cell aircraft

The Antares DLR-H2, the first piloted aircraft in the world capable of taking off using power provided by fuel cells alone, now has a successor – the Antares H3. The aircraft has been developed by DLR in collaboration with Lange Research Aircraft GmbH and is expected to set new records for flight duration and range. The maiden flight will be in 2011. The hydrogen fuel is used to generate electricity in a direct electrochemical reaction with atmospheric oxygen, without combustion. Water is the only by-product of this reaction; no particulates are created. If the hydrogen used in the fuel cells is produced using renewable resources, the aircraft can fly carbon neutral.

[www.DLR.de/TT/en](http://www.DLR.de/TT/en)  
[www.lange-aviation.com](http://www.lange-aviation.com)



The Antares H3 will set new records in flight duration and range

### Fresh Photons

Idiosyncratic, illuminating and only occasionally disgusting, this is a Tumblr-based collection of science images from around the world and beyond. Updated daily to live up to its name, Fresh Photons makes for an excellent browsing companion with that mid-morning coffee.

<http://freshphotons.tumblr.com>

### Mars WebCam

The Mars WebCam - Visual Monitoring Camera to give it its official title - is an ordinary camera in an extraordinary place, attached to the Mars Express spacecraft orbiting the red planet. Equivalent to a PC webcam, it was originally intended to gather visual telemetry for mission controllers to observe the separation of the ill-fated Beagle-2 lander, but has since taken on a life of its own, returning new images on a regular basis to demonstrate what an astronaut would see from the same position.

<http://www.esa.int/vmc>

### Real-time lightning map

Watch lightning storms drift about our continent in real time. This website shows the latest results from the European Cooperation for Lightning Detection (EUCLID) network, comprising 75 lightning detectors in 13 European countries, employed operationally for meteorology, aviation safety, insurance and many other scientific and industrial applications.

<http://www.euclid.org/realtime.html>

### Daily view into space

Spectacular, breathtaking or just beautiful – the 'Astronomy Picture of the Day' published by NASA gives new insights into the vastness of the universe, with clear, concise explanations for each image.

<http://apod.nasa.gov>

### For space fans

Anyone who is looking for space information or images will be drawn here. ESA's Science and Technology website has everything: mission descriptions, spacecraft models and particularly impressive images. The readership level ranges from easily understood concepts to serious science – there is something for everyone.

[www.sci.esa.int](http://www.sci.esa.int)



# From Antarctica to space

Astronauts and polar researchers have one thing in common: they live and work in extreme conditions. Both astronauts on the International Space Station and scientists in the Antarctic have to endure confined conditions and months-long isolation. Apart from weightlessness, living conditions in an Antarctic station and in space are quite similar and this provides space physiologists with a unique opportunity. In a collaboration between DLR and the Alfred Wegener Institute for Polar and Marine Research, physiologists in Germany's Neumayer III Antarctic station are examining the effects of extreme living conditions on the health and productivity of its inhabitants. Initial results from Antarctica have already proven to be of great interest for spaceflight.

## Space physiologists are researching astronaut health problems in Antarctica

By Jonathan Focke

### The collaboration

In November 2009, DLR, in its role as Germany's Space Agency, concluded an agreement with the Alfred Wegener Institute for Polar and Marine Research to collaborate on future health research. The Institute provides the infrastructure, staff – including the station physician – and the subjects as well as the transportation logistics needed to work on the German Neumayer III Antarctic station. DLR supports the physiologists' research in Berlin and Munich through grants to their universities, coming from funds allocated by the German Federal Ministry of Economics and Technology.

Physical fitness is a must for anyone wishing to perform research under extreme living conditions. This is as true for astronauts on the International Space Station as it is for polar researchers in the Antarctic. "Preservation of the team's health and performance is crucial," explains Günter Ruyters, Head of the Life Sciences Programme at the DLR Space Agency in Bonn. Space physiologists such as Hanns-Christian Gunga of the Charité Berlin and Alexander Choukèr of the Ludwig Maximilian University in Munich are examining the effects of isolation, confined conditions, restricted mobility and weightlessness on astronaut health. With their 'THERMO' and 'IMMUNO' experiments, the researchers are investigating how life in space impacts thermoregulation and the behaviour of the circulatory and the immune systems of astronauts on the International Space Station.

However, one need not go to space to study certain aspects of health, as conditions similar to those on the International Space Station can be found in research stations in the Antarctic. Extreme cold, long isolation and prolonged operations within a confined space in a hostile environment are among the factors that make polar research stations such as Neumayer III intriguing for space physiologists. Ruyters adds "It was natural for the researchers to establish contact with colleagues at the Alfred Wegener Institute for Polar Research a few years ago, so as to explore possibilities for research in the Antarctic together."

Since 2009, Gunga and Choukèr have been performing experiments not only in space, but also in the Antarctic. Their experiments on the International Space Station parallel their Antarctic work: in both cases the physiologists are examining the functioning of human circulatory and immune systems under conditions of isolation. At Neumayer III, the scientists who overwinter there serve as test subjects. "While there may be up to 40 people living and working at the station during the Antarctic summer, there are, at most, only nine people there during the winter," says Ruyters. Those overwintering stay at the station for 14 to 15 months and maintain radio contact alone with the outside world for nine months. In contrast to isolation experiments such as Mars500, isolation at this Antarctic station is not simulated but real.

The German Antarctic station Neumayer III: the researchers overwintering here are isolated for nine months – a welcome laboratory for space physiologists

## The Neumayer III research station – high-tech on ice

The German Neumayer III Antarctic station of the Alfred Wegener Institute for Polar and Marine Research entered operation in February 2009. This ultra-modern construction where scientists both live and work lies on the Ekström ice shelf in Atka Bay at the north-eastern end of the Weddell Sea.

Climate researchers, geologists and other scientists take meteorological readings, track atmospheric concentrations of trace gases such as ozone, and research geophysical shifts and movements of the ice shelf and earthquakes. Around 100 containers with laboratories, living quarters, a kitchen and a hospital are housed within a protective enclosure on a platform above the snow.

Neumayer III can compensate for rising snow levels through a hydraulic elevating mechanism. The ice shelf meets the sea 16 kilometres away, where supply ships can berth.

In 1981, the Alfred Wegener Institute for Polar and Marine Research erected its first Antarctic station, the 'Georg von Neumayer', on the Ekström ice-shelf as a scientific observatory for geophysics, meteorology and atmospheric chemistry. Since, over the years, it sank into the snow and ice, the Neumayer II station superseded it in 1993. The German Federal government agreed to the construction of the Neumayer III station in 2004.

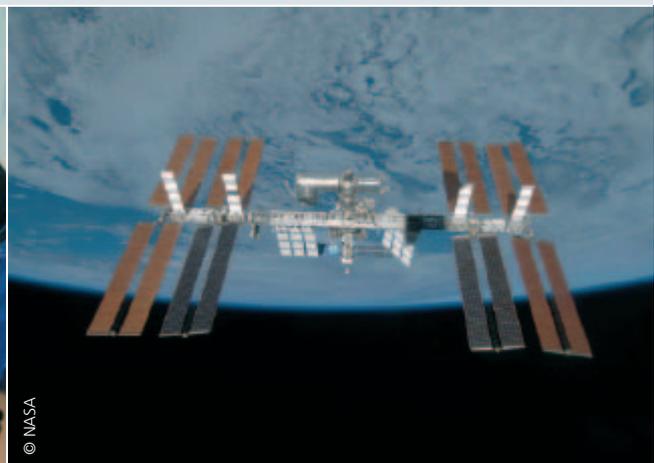
© Alfred-Wegener-Institut



Researchers are studying the physical and psychological effects of long-term isolation on the teams at the Neumayer III station



Alexander Choukèr of the Ludwig Maximilian University in Munich taking a blood sample in the Antarctic station



© NASA

Isolation studies corresponding to those on the Neumayer III station are being carried out on the International Space Station at the same time

Alongside their investigations of the circulatory system, Gunga and his team at Charité Berlin are also looking into blood cell formation, fat and muscle mass effects, as well as activity and sleep behaviour in their subjects. They are not on site themselves, so the Neumayer III station's physician serves as their proxy. He examines the circulation, and muscle, fat and fluid composition of the subjects at regular intervals. This data is then transmitted by satellite to Berlin and evaluated by Gunga.

Blood samples are also regularly taken from the subjects overwintering at the station. "These blood samples are deep frozen and then transported to Berlin under refrigeration at the end of the winter sojourn," explains Ruyters. There they are examined for the concentration of certain hormones, with any modification in the levels of the Erythropoietin hormone being of particular interest. Erythropoietin is responsible for the production of red blood cells in the human body, which supply the body with oxygen. "Normally, the level of Erythropoietin in human blood remains constant, though samples taken from astronauts during space missions have revealed significant fluctuations," explains Gunga. "In some astronauts, the hormone has been barely discernible for brief periods; however, its concentration is fundamentally linked to the astronauts' performance." Reduced Erythropoietin equals reduced oxygen and reduced performance. Why it decreases in space has not yet been established, but the long-term investigation at Neumayer III, the first ever research programme of this type, hopes to uncover this. Some results are already known: Erythropoietin concentration in the blood of subjects reaches a minimum during the winter months of total darkness; a reduction is not only observable during weightlessness in space. Establishing the reason for this will be the next decisive step, Gunga reckons.

Meanwhile at Ludwig Maximilian University in Munich, Choukèr aims to explore a further problem in space medicine through Antarctic research: it has long been known that astronauts' immune systems become impaired in orbit, eventually recovering once back on Earth. The precise reason for this remains unclear. Choukèr is examining the effects of prolonged isolation on the immune systems of overwintering subjects by taking blood samples. He then compares these results with those from another overwintering group at the Franco-Italian Concordia Antarctic station. While Neumayer III is at sea level, Concordia lies at an altitude of 3200 metres, introducing a further stress factor: reduced oxygen in the air. "This relative situation is unique," says Choukèr. "With this comparison, we can ascertain which symptoms can be attributed to the lack of oxygen and not merely to isolation. With the help of data from the International Space Station, we can zero-in on the role of weightlessness." There are engineering requirements to maintain oxygen in the habitats of missions to the Moon and Mars at the lowest possible levels, so these results will be extremely important for spaceflight.

A second experiment being carried out by Choukèr also has practical benefits for 'normal' patients. Apart from examining their blood, the physiologists also examine the air exhaled by their subjects. A myriad substances are found in exhaled air, of which only a few have been definitively characterised so far. "The substances in the air may provide insights into the metabolism of the organism," says Choukèr. "For instance, certain molecules in exhaled air develop during the inflammation process of an organ, and may be detected with an analysis instrument." By cross-checking with blood samples, Choukèr and a team of researchers and partners from industry are looking to better characterise individual substances. He hopes that one day, exhaled vapour analysis may even replace the current method of taking blood samples in a clinic to assess the condition of individual organs.

The scientists are hoping for valuable results from their research in the Antarctic over the next few years. "This work should lead to a comprehensive overview of the physiological and psychological changes that occur in a person in extreme environments," explains Ruyters. "These findings will not merely be significant for overwintering in the Antarctic or for long-duration missions in space." The research should also bring about an improved understanding of metabolic and circulatory regulation and immune system behaviour in healthy individuals as well. Ruyters adds, "Research in an icy environment and on the International Space Station turns out to be absolutely relevant for people living in normal conditions too." ●



### Hanns-Christian Gunga

Hanns-Christian Gunga was born in 1954 and studied geology and palaeontology in Münster, before concluding his medical studies and receiving his doctorate in 1989 from the Freie Universität Berlin. Since 2004, he has been a Professor at the Institute for Physiology at Charité Berlin. His research has focused on space medicine, blood, heart, circulatory and renal physiology, and comparative physiology in extreme environments. Gunga is also the spokesperson for the Centre for Space Medicine in Berlin, founded in 2000. He advises ESA as well as the North Atlantic Treaty Organisation.



### Alexander Choukèr

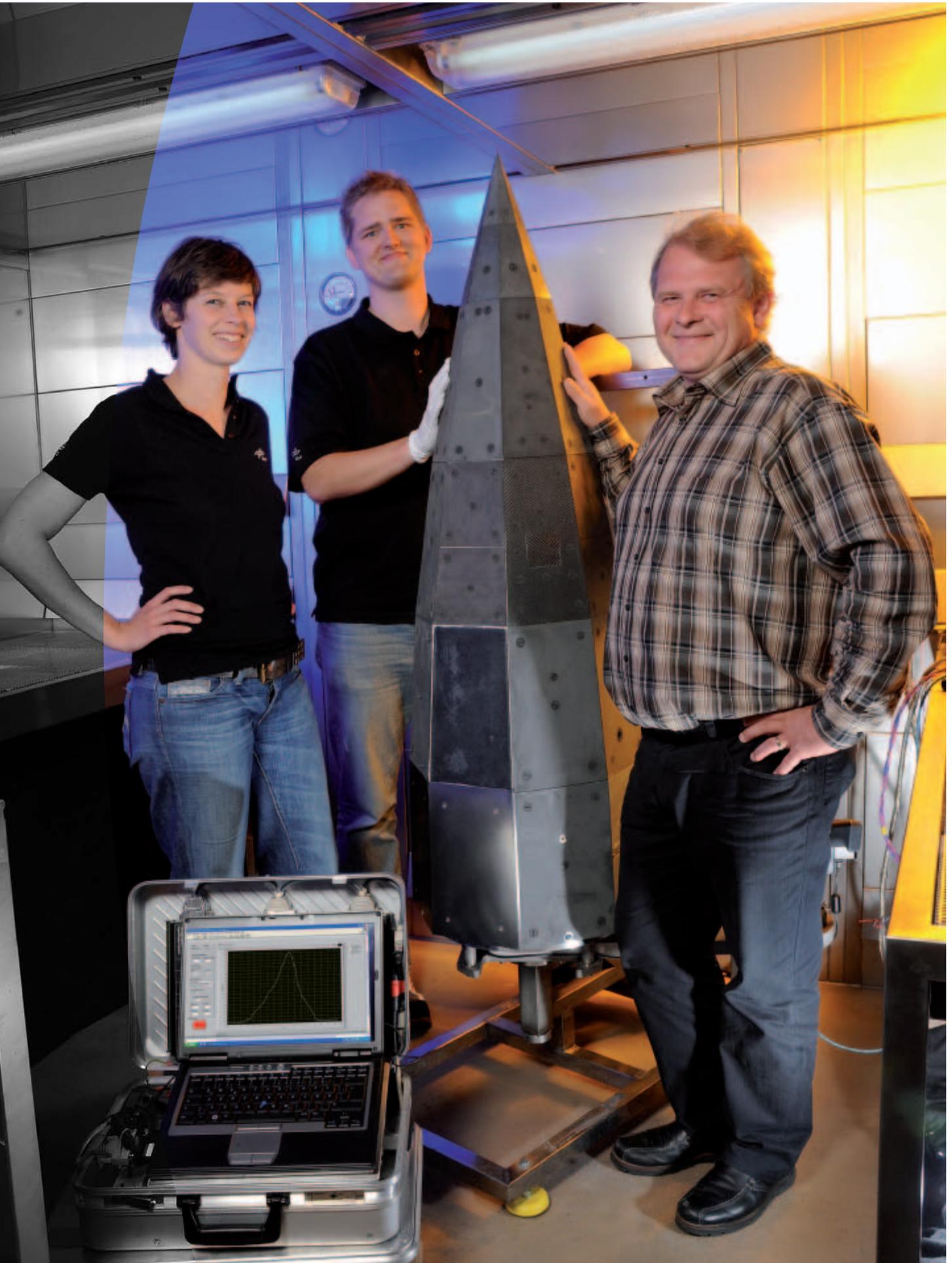
Alexander Choukèr, born in 1969, studied medicine and received his doctorate at the Ludwig Maximilian University in Munich, where he is a Senior Physician and Group Leader at the Clinic for Anaesthesiology. His research has focused on the stress-dependent variables of the immune system. He participates in various DLR, ESA and NASA research projects and advises ESA in his position as Chairman of the Life Sciences Working Group.

### About the author:

Jonathan Focke is a student of science journalism at the Technical University of Dortmund and was an intern in DLR's Corporate Communications Department from July to September 2010.

### More information:

[www.awi.de/en](http://www.awi.de/en)  
[www.DLR.de/rd/en](http://www.DLR.de/rd/en)



# A breath of fresh air for re-entry technology

A new German project with the potential to unlock novel possibilities for spaceflight, DLR has developed the experimental Shefex II spacecraft that promises to make flying to space and back safer, cheaper and more flexible. This aerospace project utilises innovative technologies including a sharp-edged heat shield with actively cooled elements.

## Angular-design spacecraft Shefex II set for space

By Jens Wucherpennig

Shefex II, which stands for Sharp edge flight experiment, is expected to take off from Woomera in Australia at the beginning of 2011. It is a unique spacecraft in more ways than one. Even at first glance, the differences when compared to previous spacecraft are immediately apparent. Compared to re-entry vehicles of today, its outer skin is angular rather than rounded, and for the first time in spaceflight, Shefex II will test an actively-cooled heat shield. In addition, it is the first actively-controlled spacecraft with re-entry capability that has been built and financed by Germany alone.

The two-metre long spacecraft has undergone comprehensive testing during its three-year development programme. During autumn 2010, it will be mounted on a two-stage sounding rocket at DLR Oberpfaffenhofen. The rocket will be launched from the Woomera test site in Australia in early 2011. This second flight in the DLR Shefex programme will test the spacecraft's angular design, its novel thermal protection and innovative control system.

### Like a flying wind tunnel

Numerous sensors will measure the aerodynamic effects and behaviour of the spacecraft during re-entry into the atmosphere – one of the most critical moments in spaceflight. Like a flying wind tunnel, Shefex II is expected to deliver additional data to aid further development. At the core of this cutting-edge technology are 160 sensors that have been integrated by DLR's Supersonic and Hypersonic Technology Department in Cologne. These are intended to monitor the pressure, heat flow, and temperature at the tip of the payload during the flight. Their findings concerning the processes affecting the craft's external skin, at temperatures that are expected to exceed 2000 degrees Celsius, will be the most valuable results of the flight experiment.

Shefex II will test nine different thermal protection systems making up its multi-faceted outer skin, which are largely the result of the development of fibre-reinforced ceramics by DLR in Stuttgart and Cologne, and well as experiments by German aerospace industry (Astrium and MT Aerospace) and international partners.

The heart of Shefex II – the angular nose cone after assembly in Stuttgart; (from left to right) Hannah Böhrk, Henning Elsäßer and project manager Hendrik Weihs stand beside their experimental re-entry vehicle. They are looking forward eagerly to the launch of the new spacecraft in early 2011



Shefex gradually takes shape



The last of the rectangular heat shield tiles being mounted



The faceted shape of the thermal protection also promises better aerodynamics

### Germany at the cutting edge

“Germany is playing a pioneering role in advanced re-entry systems,” explains Hendrik Weihs, a researcher at DLR’s Institute of Structures and Design in Stuttgart and Project Manager of the national Shefex programme. His view of the future sees a possibly manned European spaceflight programme. The idea behind Shefex is to use its experimental flights to explore new re-entry technologies as economically as possible. To pursue this goal, the test vehicle will be launched on a relatively low-cost sounding rocket.

Its predecessor, Shefex I, was launched from the north of Norway in 2005 on a combination of a Brazilian VS-30 lower-stage rocket and a Hawk upper stage. Following its launch, Shefex I reached an altitude of 211.5 kilometres over the Norwegian Sea and re-entered Earth’s atmosphere at almost seven times the speed of sound – fast enough to generate temperatures of 1600 degrees Celsius at the sharp leading edge of the payload. These temperatures are typical for a spacecraft as it re-enters Earth’s atmosphere. During re-entry, the experimental body remained coupled to the upper stage in order to utilise its fins for stabilisation.

### Valuable findings despite the loss of Shefex I

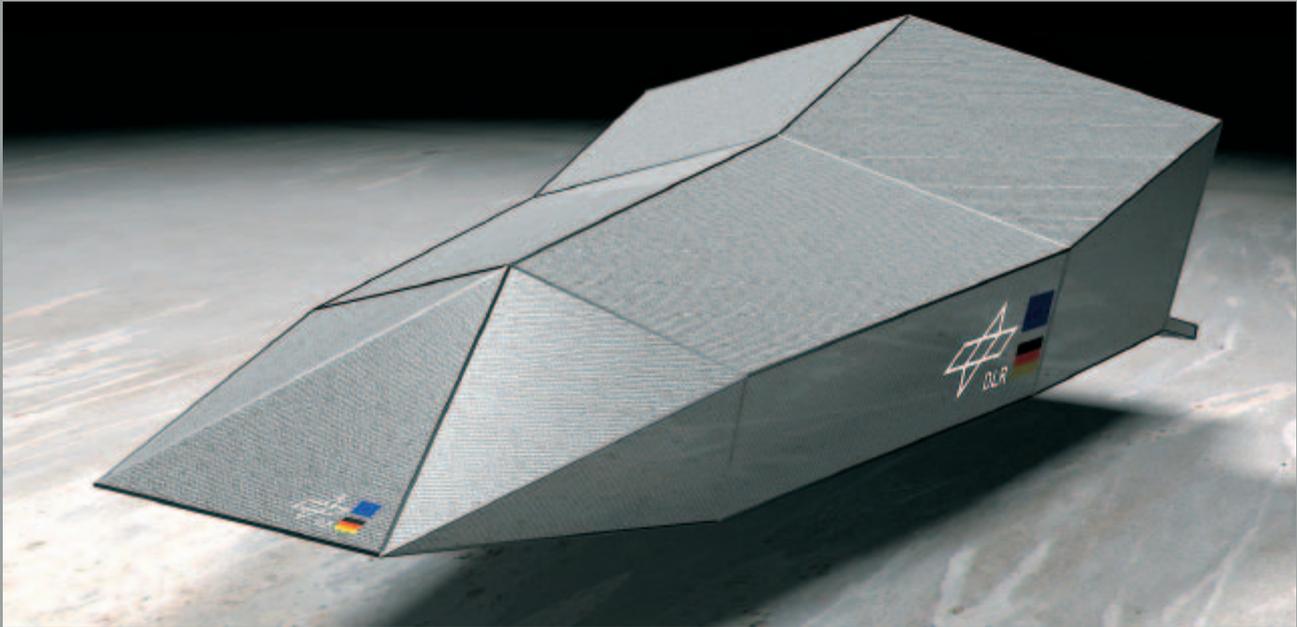
Shefex I should have splashed down after a nine-minute flight, some 200 kilometres from the launch site. However, the real-time video transmission from the rocket revealed that the recovery system – a parachute and buoyancy device – had been deployed too early, at too high a velocity. Shefex I was lost at sea, but the mission was still a success because of the valuable data that it sent back; besides, recovery was only an add-on option and not a primary mission goal. Analysis of the test results confirmed that the high cost of the complex, shaped components used in the test device’s construction could be reduced drastically by replacing them with flat panels. This simplified configuration could potentially lead to significant cost savings during maintenance and replacement of damaged components on future reusable vehicles along Space Shuttle lines. With a relatively modest budget – approximately four million Euro, the larger part of which was spent on the experiment and not its carrier – excellent results were achieved.

At 12.6 metres in height, the rocket that will carry Shefex II is a larger Brazilian model, selected to achieve a higher velocity – up to 12,000 kilometres per hour. In contrast with its predecessor, Shefex II boasts small moveable wings, called canards, for flight control. The launch from Woomera should take Shefex II to an altitude of 200 kilometres. The descent and re-entry into Earth’s atmosphere – at altitudes of 100 to 20 kilometres – interests the researchers the most. The vehicle’s subsequent landing in the desert with the aid of a parachute will ensure that the spacecraft can be recovered.

Also in contrast to its predecessor, Shefex II will be actively steered upon re-entry. DLR has developed a custom aerodynamic flight control system that will guide the spacecraft as it returns to Earth. The key components of the ‘Canard Control System’, designed by DLR researchers at its Institute of Flight Systems in Braunschweig, are the canard control surfaces mounted near the front of the craft, which provide active guidance. Initial ground tests have been conducted successfully.

### Landing in Germany also a possibility

The objective of the Shefex programme is the creation of a novel orbital glider called ‘REX Free-Flyer’, to be available for conducting experiments under zero gravity conditions from 2020. This vehicle might have come from a science-fiction film, and is perhaps the harbinger of future space travel. Its angular shape promises two significant advantages. Firstly, its heat shield can be simpler and safer, and secondly, its faceted shape provides improved aerodynamic properties. “Application of Shefex technology will enable a relatively simple design and therefore a low cost orbital glider, with precision landing capabilities like the Space Shuttle,” says DLR project head Weihs. “From the technical point of view, REX will be able to land at any normal airport or airfield in Germany.” This technology opens the door to numerous future applications. Re-entry technology lies at the heart of many space missions, ranging from sample-return journeys – for example, the collection of samples from the Moon or Mars – to manned re-entry vehicles, forming part of a fully or partially reusable space transportation system. This new technology could also be of interest for space tourism.



The vision of the SHEFEX developers – a novel small space plane called 'REX Free Flyer'. It will be available from 2020 for retrievable experiments under weightless conditions

#### Expertise from various DLR institutes

The aerodynamic design is a result of computer simulations of flow characteristics and tests in various wind tunnels performed at DLR's Institute of Aerodynamics and Flow Technology in Braunschweig, Cologne and Göttingen. Researchers in Cologne are in charge of payload instrumentation. The Shefex II experiment itself has been developed, manufactured and integrated by the DLR Institute of Structures and Design in Stuttgart, while personnel from DLR's Institute of Flight Systems in Braunschweig are responsible for the flight guidance system. DLR's Mobile Rocket Base, Moraba, in Oberpfaffenhofen is responsible for the rocket and launch, while the newly established DLR Institute of Space Systems in Bremen is providing a navigation experiment. ●

#### About the author:

Jens Wucherpennig is a Communication Officer at DLR's Göttingen facility.

#### More information:

[www.DLR.de/en/shefex](http://www.DLR.de/en/shefex)



### Shefex II vital stats

<b>Planned launch date</b>	Beginning of 2011
<b>Height of the complete launcher</b>	12.7 metres
<b>Length of the angular Shefex forward body</b>	2.1 metres
<b>Launch mass</b>	6800 kilograms
<b>First stage burn duration</b>	62 seconds
<b>Second stage burn duration</b>	70 seconds
<b>Maximum flight altitude</b>	200 kilometres
<b>Duration of experimental phase</b>	53 seconds (from 100 to 20 kilometres altitude)
<b>Distance between launch and landing sites</b>	800 to 900 kilometres
<b>Maximum speed</b>	Mach 10 (about 12,000 kilometres per hour)



# Material solutions to energy industry's hottest topics

There are several paths to safer and more environment-friendly energy supply; DLR's energy researchers are weighing the various options. For example, they are working on more efficient power plants and energy storage, so that energy can be made available as it is needed, and are developing processes to produce power and fuel from sunlight. For their new methods and processes, the researchers need new materials. A filament-reinforced ceramic developed by DLR has the potential to make many processes within the energy industry more efficient, or simply bring them into the realm of possibility for the first time. At DLR Headquarters in Cologne, energy and materials researchers will, in future, be working under a single roof at the Competence Center for Ceramic Materials and Thermal Storage in Energy Research, CeraStorE. There, they want to improve existing ceramic materials, develop new ones and run trials in larger installations, with the aim of forging a critical link between research and production.

## Energy and materials researchers to work together under one roof at the new CeraStorE competence centre at DLR Cologne

By Dorothee Bürkle

### CeraStorE in brief:

- Two large laboratory and technology halls
- Around 10 smaller laboratories and 10 offices
- Inauguration scheduled for late 2011



The north side of the CeraStorE complex

Heat resistant and unbreakable – a combustion chamber tile made of the fibre-ceramic composite material WHIPOX®, developed at DLR

Stefan Reh, Managing Director of the DLR Institute of Materials Research, has enormous faith in the new Whipox® (Wound highly porous oxide ceramic) material. Like all ceramics, the filament-reinforced ceramic can withstand very high temperatures, and is also corrosion resistant. At the same time, Whipox® has high tensile strength thanks to the aluminium oxide filaments incorporated within it. The material has the right stuff for cladding the combustion chambers of gas turbines. A gas turbine equipped with this material can run at higher temperatures, reducing the need for air-based cooling. Higher temperatures increase the efficiency of the turbine; combustion becomes more efficient overall and also produces less pollutants. Such gas turbines should make a significant contribution in decades to come to reducing carbon dioxide emissions. As Reh argues, "The proportion of renewable energy is growing, but fossil fuels still account for 70 percent of electricity generation. This percentage must, and will, drop in coming years, but only gradually. So in the meantime, in parallel, we have to increase the efficiency of the gas turbines we use."

It will still be some time before ceramic materials are applied to combustion chambers. "Turbine manufacturers are very interested in exploiting the properties of ceramics in their combustion chambers, but first they must be sure that the material can withstand the enormous stresses in the combustion chamber over the long term." The Institute of Materials Research has already tested the material in small laboratory experiments. Now they aim to work with their industrial partners in the new CeraStorE competence centre to develop prototypes that are close to real-world applications, which can



A new heat-storage technology under test. DLR researchers are studying the properties of powdered calcium hydroxide as a chemical heat-storage medium. The picture shows heating wires being attached to a storage reactor. The calcium hydroxide is located inside these reactors, which are equipped with thermocouples

be tested under conditions similar to those of their intended application. "We have always been surprised positively by our material in short-term tests. Our combustion chamber tiles have survived under higher stresses than we expected," added Reh. This is why the researchers want to develop simulation methods and models in the competence centre, to better understand the behaviour of the material and exploit the limits of its resistance to combustion chamber conditions.

### Concentrated sunlight above 1000 degrees Celsius

Extremely high temperatures are also generated in the tower of a solar-thermal power plant. Hundreds of mirrors concentrate sunlight onto a single point, the 'receiver' at the top of the tower. At temperatures above 1000 degrees Celsius and with intense ultraviolet radiation, the material is subjected to extreme stress. Faced with this challenge, the researchers have found a heat- and corrosion-resistant ceramic that they now want to develop further, because solar-thermal power plant operators would like to operate at even higher temperatures. Before they build the new components into the receivers of their installations, they must know the mechanical properties and ageing behaviour of the new material being used. Christian Sattler from DLR's Institute of Technical Thermodynamics sees enormous potential in the fact that energy and materials researchers will be working together at CeraStorE in development and testing: "CeraStorE will enable us to create synergies and take on a whole new range of challenges. Materials scientists work on basic research and improve the ceramic materials – for the solar receiver, among other applications. The energy researchers can then develop the receiver itself, and integrate it into the power plant."

The researchers want to improve the material's resistance to fracturing by using monolithic ceramics together with filament-reinforced oxide ceramics. "The aim of this collaboration is to develop new receivers at CeraStorE, test them at the research towers in Jülich and Spain, and finally engineer them for production and application together with industry," says Sattler.

### Functional ceramics – hydrogen from water and sunlight

In a solar-thermal power plant, a ceramic receiver converts sunlight into heat, which is used for power generation – but ceramics have the chemical potential to do more. In solar hydrogen generation, such as with DLR's 'Hydrosol' process, the ceramic material plays a central role. A reactor on the solar tower, lined with this material, splits water into its components hydrogen and oxygen. In a first reaction, which takes place at less than 1000 degrees Celsius, the functional ceramic absorbs oxygen atoms into its crystalline structure. In a second reaction, at about 1200 degrees Celsius, the oxygen is released and then the reactor is recharged. This hydrogen production process has been shown to work repeatedly. Energy and materials researchers want to develop it further to improve the hydrogen yield and lifespan of the reactor.

### Energy on demand

Alongside ceramics, CeraStorE will also develop and test new energy storage technologies. Energy storage plays a key role in the energy industry, and wider use of renewable energy will not be feasible without it. It is important that the storage systems are economical and suitable for adaptation to real-life applications. On the basis of their many years of experience, the researchers will further develop existing storage technologies and investigate new solutions, testing them in close-to-application conditions. With thermochemical storage systems, the



Different heat-storage techniques at temperatures of up to 400 degrees Celsius are studied in this 10-kilowatt pilot plant. The storage tank and its external insulation, visible to the left, has a capacity of 100 litres and can be operated with different salt-based liquid media. In the foreground, to the right, is the thermal oil system, used for supplying or removing heat during the charging and emptying of the storage tank



The Small Solar Power System tower at the Plataforma Solar de Almería, Spain. The reactor is heated to 800 to 1200 degrees Celsius by concentrated sunlight. Hydrogen is extracted from water at these temperatures

researchers are moving into almost completely unexplored territory. These systems are able to store heat as chemical energy. In everyday life, we see this in the burning and slaking of lime. When it burns, lime takes up heat in an endothermic reaction, in which carbon dioxide is driven out of the calcium carbonate and calcium oxide is generated. When burnt lime is slaked with water, an exothermic reaction releases heat and generates calcium hydroxide.

Thermochemical storage systems based on this principle hold promise, above all, because they offer very high energy density. For instance, the chemical reaction of the limestone cycle can store more than five times as much energy per cubic metre as water being heated and cooled between 30 and 80 degrees Celsius. Furthermore, the energy can be stored for as long as is required, a feature that opens up whole new scenarios for energy storage. A storage system of this kind could be located directly on the power station premises, such as large molten salt storage tanks currently used in solar-thermal power plants. The researchers want to develop such innovative new storage technologies at CeraStorE before readying them for the market with their industrial partners.

Along with thermochemical storage, the energy researchers will further develop molten salt storage techniques at CeraStorE. A two-tank system with 28,500 tons of liquid salt is already being used to store heat energy at the Andasol

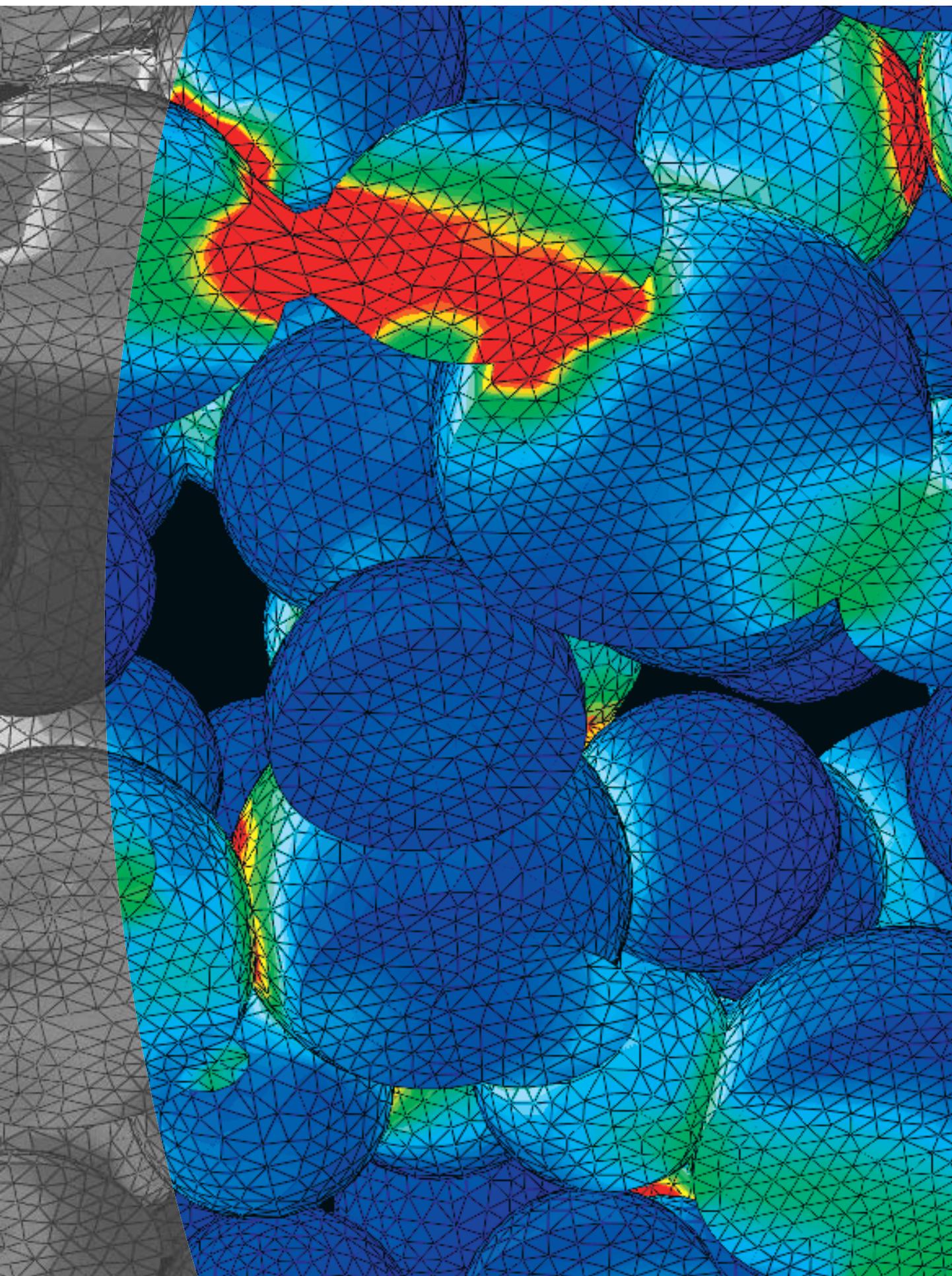
solar-thermal power plant in southern Spain, making the station a reliable energy source even at night or during cloudy days. This storage concept will be developed further to make it cheaper and more efficient, for example by using new salts with lower melting points that can also be heated to higher temperatures, or by bulking out the salt with cheaper filler materials. Here too, the researchers will be using the CeraStorE laboratories and testing their concepts in test facilities that closely match their intended applications. ●

#### About the author:

Dorothee Bürkle is an Editor in DLR's Corporate Communications Department, working on the field of energy research.

#### More information:

[www.DLR.de/BK/en](http://www.DLR.de/BK/en)  
[www.DLR.de/TT/en](http://www.DLR.de/TT/en)



# It's all in the detail

It seems obvious – a component is only as good as the material it is made from. Even when newly-developed materials might seem unlikely to provide any surprises when put under stress, their practical performance all comes down to the detail. It is the microscopically small structures in a material that determine whether or not a component should be put to use. DLR's Institute of Materials Research analyses and assesses high-performance materials for the aerospace industry. Researchers at the Institute apply combinations of experimental and numerical methods or even develop completely new approaches to special problems in materials science.

## Computer modelling and virtual testing of new materials

By Marion Bartsch

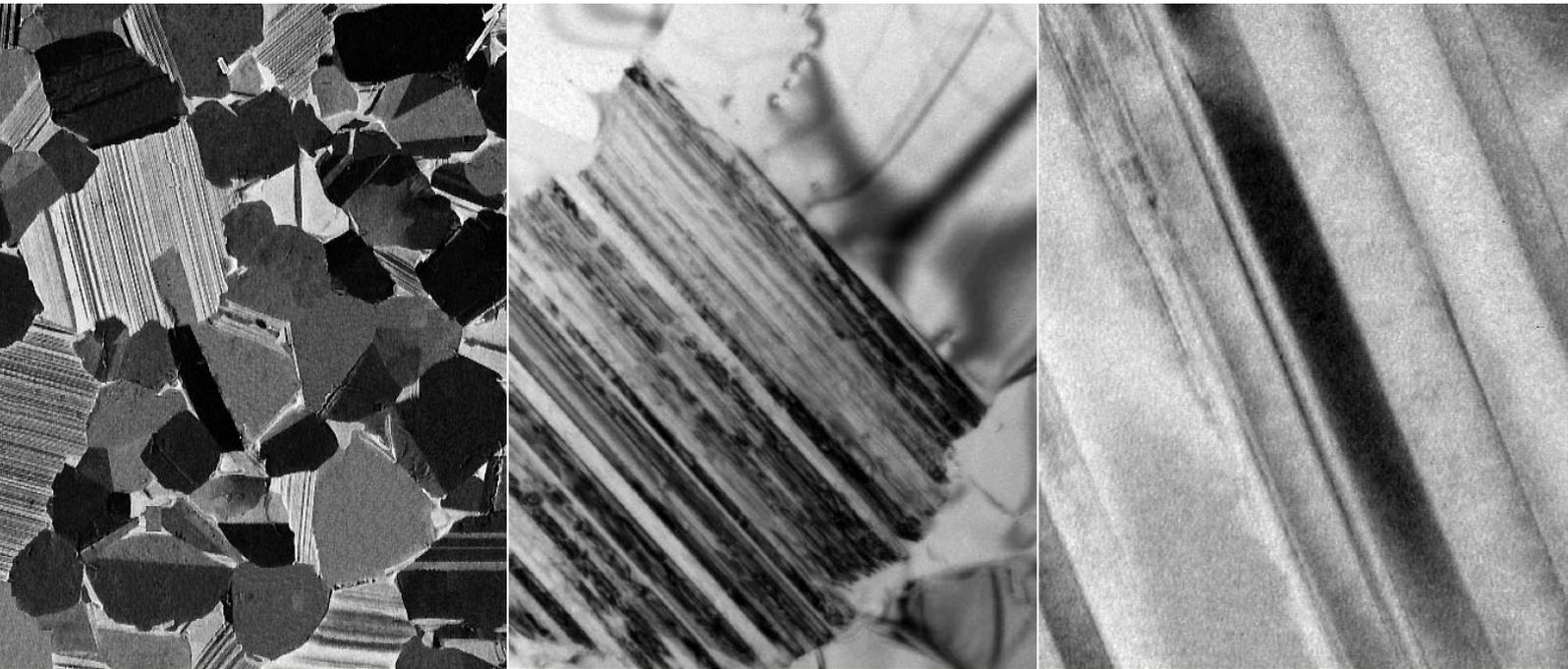
### In brief

When generating computer models of new materials, they are depicted precisely, at scales ranging from nanometres to centimetres, using microscopic and micromechanical methods. Researchers can generate numerical models with data acquired experimentally. These models are then used to simulate the behaviour of laboratory samples or simple components under quasi-operational loads. The calculations are checked in corresponding laboratory tests.

Components for the aerospace industry are expected to be light and reliable, even under extreme conditions. New materials play a significant role in achieving higher performance levels, improved efficiency and reduced fuel consumption. Yet, many of these are put under much less stress during operation than they are capable of withstanding, because it is not entirely clear whether they will remain reliable. When designing and assessing components and materials according to standard criteria, it cannot be guaranteed that components will not fail in certain circumstances. Therefore designers err on the side of caution and use higher safety factors, and it becomes accepted that a material's potential will not be exploited fully.

One example of this is the titanium aluminide blades used in aircraft gas turbines. These intermetallic alloys are noted for their stability at high temperatures while also having a low density, which makes them very light. Their disadvantage is a tendency to undergo brittle fracture. Localised stress build-up is not reduced by plastic deformation, and in the worst case will cause the component to fail. Under the microscope it becomes apparent that the material consists of multiple small crystals or grains. Under the scanning electron microscope even finer structures are visible. In what are referred to as 'duplex alloys', some grains are homogeneous while others are further split into fine thin layers, or 'lamellae'. The mechanical properties of these different crystalline areas are direction-dependent. The spatial orientation of the individual areas, known as phases in the technical terminology, can be determined under the transmission electron microscope. Preferential orientation, which is the alignment of the crystalline phases in a specific direction (as can occur in the material during manufacture, for example, while being forged), can be determined with X-ray diffraction. The construction of a material as seen under the microscope – the microstructure – is characterised by the spatial arrangement of the phases such as grains and lamellae. This occurs more or less randomly during manufacturing.

Numerical model of the matrix of the ceramic composite WHIPOX®. The image shows the local stresses that appear during a compression test. Red areas are under tensile stress while blue areas are under compressive stress



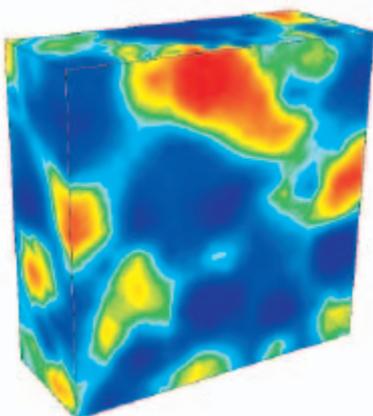
Images of a titanium aluminide alloy with duplex microstructure at various magnifications. The different areas of the microstructure can be detected in the scanning electron microscope at a magnification of approximately 2000. The striped areas consist of lamellae of various crystal phases that are identified and measured at higher magnifications with a transmission electron microscope

When phases with different spatial orientations adjoin one another, they respond differently to a globally homogeneous load. This causes localised stress differences. In crystallites that are unfavourably oriented with respect to the mechanical load, this can lead to high levels of localised stress, causing the sample or component to break. Accordingly, failure under a surprisingly low load is not caused by a defect in the material, but by an unfavourable local configuration in the material's microstructure. The effects of such unfavourable configurations on the behaviour of the component need to be calculated so that they can be assessed.

Calculating a material's behaviour requires three-dimensional computer modelling, due to the complex microstructure. To do this, first a geometric model of the material's microstructure is built. This must represent grain diameter, lamella width, volumetric content, spatial orientation and distribution of the phases. Then the appropriate, directionally-dependent mechanical properties are allocated to the individual phases. These properties are determined in laboratory experiments on samples of pure phases or single crystals, in the form of constitutive equations. Such an equation describes, for example, the deformation of a material caused by an applied load. Simulations are performed on the three-dimensional computer models, also

known as numerical models, in which virtual mechanical loads are applied to the model in the computer. The model represents a virtual material sample. The result of the computations can be given as load-deformation curves for the virtual sample of the modelled material and local stresses that occur in the material at microstructural levels.

So how is the model of the material entered into the computer? In the Department of Experimental and Numerical Methods at DLR's Institute of Materials Research in Cologne, these models are calculated using the Institute's own custom-written programs. This means that the researchers use the microstructure parameters such as grain diameter and the proportion of small and large grains detected in the material during microscopic research as starting points. Then, the microstructure elements are radically simplified for geometric purposes. Irregularly formed grains can be represented as cubes and described with just one geometric parameter, such as side length. From the simplified microscopic elements or using the parameters with which they are described, a corresponding virtual microstructure that has the essential geometric properties of the actual microstructure can be calculated. For microstructures with a complex structure, the skill lies in smartly simplifying all the essential microstructure components, describing them via parameters and assembling them in their characteristic spatial arrangement.



Calculated local stresses in a virtual titanium aluminide specimen under mechanical load. Red areas are under tensile stress and blue areas are under compressive stress

The major benefit of geometric material models constructed from parameters is that they can be used not only for a specific spatial configuration of the microstructure component, such as a small area of a material that has been examined microscopically. The experimentally determined microstructure parameters can be used to generate as many numerical models as required. Thus, more and more new local configurations are generated for the microstructure elements, as is the case in the actual material. In the example involving titanium aluminide alloys, the localised stress build-up for unfavourable microstructure configurations can be determined in simulation calculations. These results can then be used to better exploit the material's full potential in component design and assessment.



Marion Bartsch, shown here operating a scanning electron microscope. Microscopic details determine whether or not a material will fail

However the microstructure parameters can also be varied deliberately. Simulations on numerical material models that are generated from variations in grain size, volumetric content of individual phases and so on, indicate the influence of the various parameters on material's behaviour. Such investigations provide valuable clues for materials development, whereby a material's properties are influenced by the creation of specific microstructures.

The reliability of the model in practice will be tested through laboratory experiments. For specific load situations, such as tensile and compression testing, scientists determine the mechanical behaviour of a sample of the material experimentally and compare it with predictions taken from the simulation calculations on the numerical model, meaning the corresponding virtual sample. If the experiment and the prediction are a close match, the model is used for assessing components under operational loads. ●

#### About the author:

Marion Bartsch is the Head of the Department of Experimental and Numerical Methods at the DLR Institute of Materials Research in Cologne. She is also Professor of Materials for Aerospace Applications at the Ruhr-Universität Bochum. In the field of materials modelling, she works with Mohammad Rizviul Kabir, who is developing numerical material models for titanium aluminide, and Henning Richter, who is working on modelling the ceramic matrix composite WHIPOX®.

**More information:**  
[www.DLR.de/wf/en](http://www.DLR.de/wf/en)

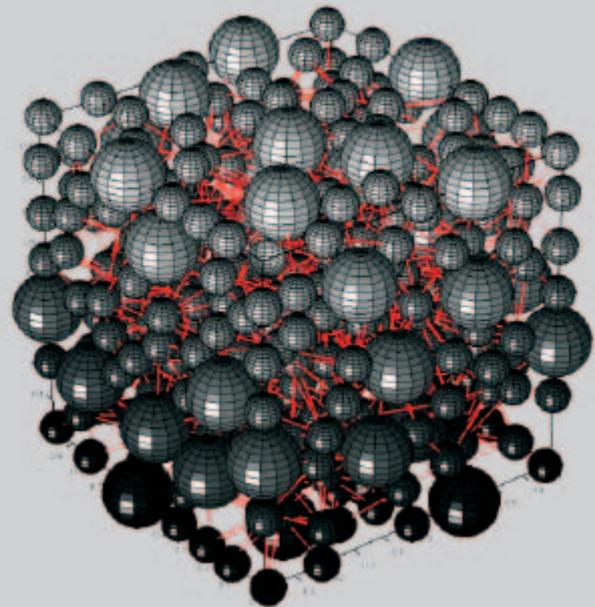
## Case study: WHIPOX®

### It does not break – but why?

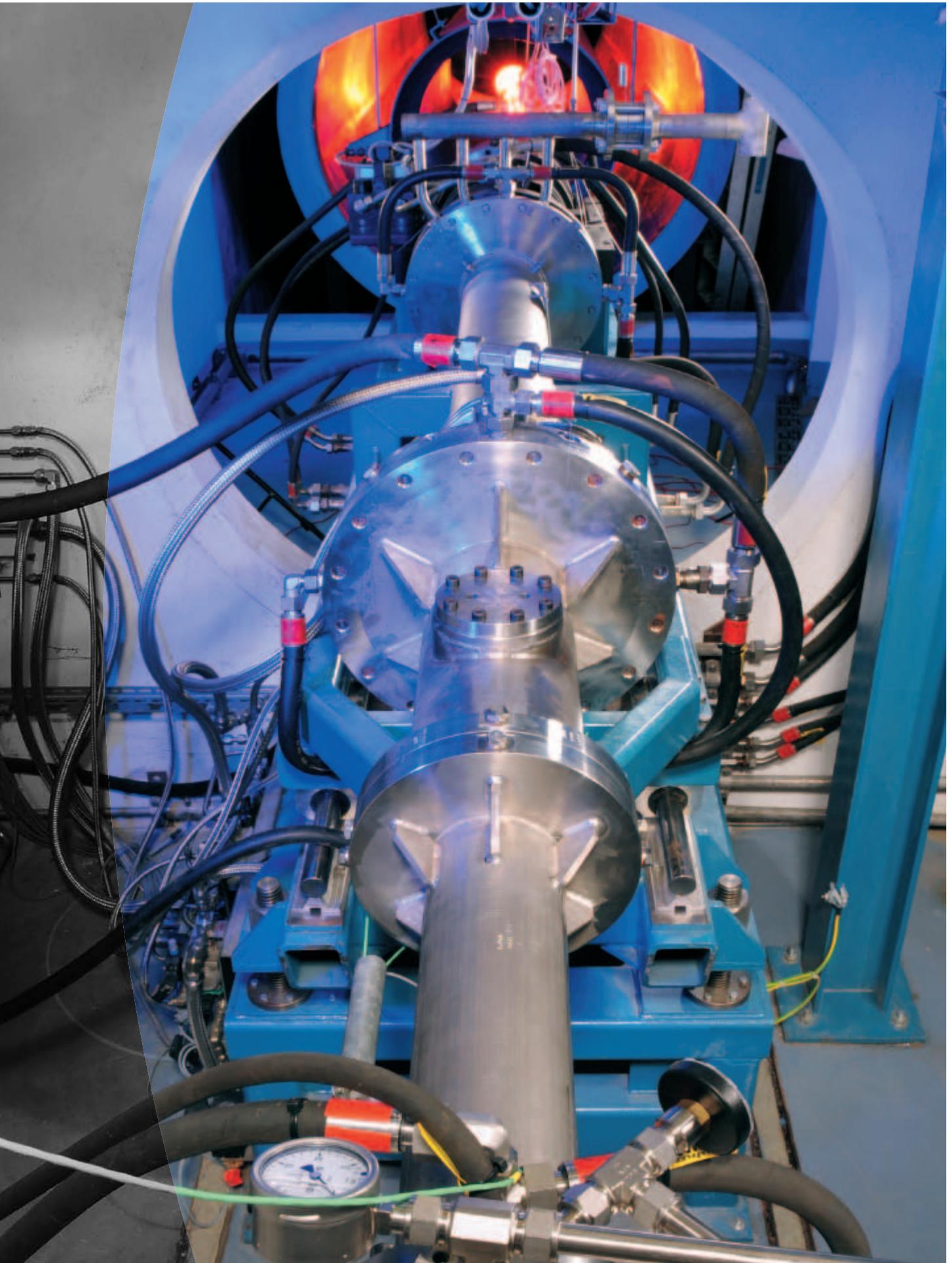
WHIPOX® (Wound highly porous oxide ceramic matrix composite) is a new ceramic matrix composite material that was developed at DLR's Institute of Materials Research. It withstands temperatures well in excess of 1000 degrees Celsius and has proven itself extremely damage tolerant. Unlike other ceramics, the material does not undergo brittle failure even under sudden-impact loads. A nail can be driven through a WHIPOX® sheet without shattering it. These extraordinary properties have been confirmed in several experiments. The material's useful behaviour has not yet been described adequately using current constitutive equations. DLR researchers are therefore generating numerical models to represent its microstructure to further improve the constitutive equations.

The high-tech material consists of long ceramic oxide fibre bundles surrounded by a porous ceramic oxide matrix. During manufacture, these bundles are deposited in regular diamond patterns via a coiling process. The fibres give the material its strength. Cracks in the porous matrix are deflected and branch out, meaning that energy is dissipated and the crack may stop. In a sense, the crack gets lost in WHIPOX®.

The geometric dimensions of the structural elements are very different. The diameters of the pores and individual fibres are of the order of microns. The diamonds from the fibre bundle deposition process vary from a few millimetres to several centimetres in size. Different models are used for the different sizes of structural constituents. The characteristics of the material at the microscopic level are later incorporated in the numerical model at the next, higher level.



Abstract model of the WHIPOX® matrix. The grains of the ceramic powders from which it is manufactured are represented as spheres and the connections between the grains are represented as rods



# Looking into the flame

The next generation of jet engines for civil aircraft will have to lower their emissions significantly. Engineers are working to achieve this with lean-burn combustors. These burn their kerosene-air mixture at lower temperatures, reducing the emission of harmful oxides of nitrogen. In the High Pressure Combustion Chamber Test Stand 1 at DLR's Institute of Propulsion Technology, researchers have collaborated with Rolls-Royce to build a combustor test rig in which they can monitor and analyse the lean-burn process closely, using lasers and cameras.

## DLR researchers gain insight into the combustor physics of next-generation low-emission aircraft engines

By Jonathan Focke

The target is an 80 percent reduction in emissions of oxides of nitrogen from air traffic. New results from atmospheric science, growing public awareness of environmental considerations and emissions-related local taxes at many airports are making this an urgent necessity. In addition, legal requirements being set for new engines are placing ever more stringent limits on emissions. "The pressure is growing," says Ulrich Meier from DLR's Institute of Propulsion Technology in Cologne. "We have to achieve a substantial reduction in nitrogen oxide emissions from future aviation engines."

Reducing pollutant emissions – especially oxides of nitrogen – has been a key concern for combustion chamber development for several decades. Without significantly improved combustion chamber technology, today's emissions of oxides of nitrogen would be much higher due to increasing process pressures and temperatures, as well as growing air traffic. However, current state-of-the-art technology does not allow further emission reductions. In fact, ongoing improvements in the efficiency of aircraft engines will lead to higher combustion chamber pressures and temperatures. "Increased temperatures greatly accelerate the production of nitrogen oxides," explains Meier. The opposite outcome should be targeted instead. Therefore, engine manufacturers have begun work on the novel concept of lean-burn combustion.

View of the exhaust section of the Big Optical Single Sector combustion chamber, looking along its measurement section. After leaving the chamber, the stream of exhaust is sampled here to measure its emissions; water is also injected to reduce noise

In contrast with conventional combustion chambers, combustion temperatures are lowered in lean-burn combustors. The ratio of air to fuel is changed to achieve this; more air is supplied to the burner for a given amount of fuel. "The air from the compressor is distributed differently throughout the chamber," Meier explains. "More air for the burner, less for the mixture in the combustion chamber. This excess of air for combustion reduces the overall temperature." With the same performance but at a lower temperature, this process produces fewer pollutants.

But lean burn, due to its increased air content, brings its own problems. "With the engine idling, the fuel to air ratio is so low that there isn't enough fuel to ensure stable combustion," says Christoph Hassa, Head of the Combustor Department at the Institute of Propulsion Technology. "The flame is simply blown out." However, a jet engine with a lean-burn combustion chamber must be able to operate over its entire power range, from idle through taxiing to takeoff and cruise. The engineers solve this problem by

integrating a second combustion zone into the lean-burn combustion chamber. This 'pilot burner' makes sure that the flame never goes out. The main burner is only turned on at higher engine outputs, and due to the lean-burn combustion process, it only produces very limited quantities of oxides of nitrogen.

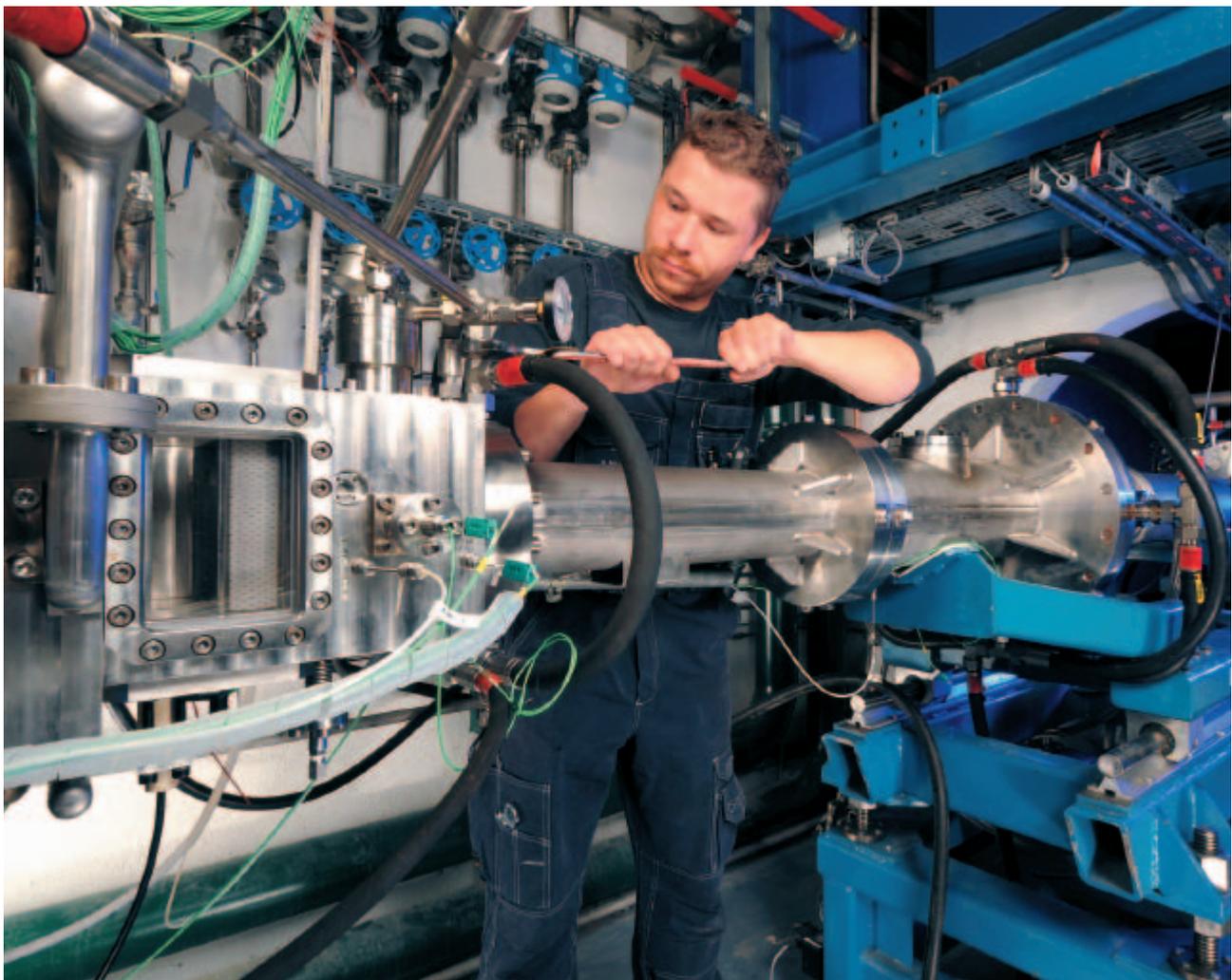
Researchers and manufacturers now have to demonstrate the reliability and cost-effectiveness of this new lean-burn

concept. Among other things, they are analysing the amount of pollutants produced, the completeness of the combustion of the fuel and the ignition of the fuel-air mixture in the chamber. "In the burner, the flow field and fuel injection must be adapted perfectly to each other," says Hassa. Achieving complete combustion of the fuel can be a problem for lean-burn

combustion burners. "For an engine to be efficient, it must burn at least 99 percent of the injected fuel," says Ulrich Meier. "This is harder to achieve at the low temperatures typical of lean-burn combustion than in conventional engines."

"This is the only lean-burn combustion chamber that we can see into, and the fact that it is full-sized makes it easier for us to transfer the results of our research to real engines"

*Leif Rackwitz, Rolls-Royce Deutschland*



DLR engineer André Mögelin carrying out installation work in the measurement section of the Big Optical Single Sector combustion chamber, one of only a few worldwide. It is possible for researchers to look into its combustion chamber (visible to the left) with cameras and lasers to study the flow and combustion in detail

For all these reasons, the researchers want to investigate the combustion chamber processes as precisely as possible. To enable this, DLR and the engine manufacturer Rolls-Royce have built a lean-burn sector combustor for full-size injectors which has been operational since October 2009. What cannot be achieved with normal aircraft engines has become possible at DLR. With the new Big Optical Single Sector, BOSS, combustion chamber, researchers can actually see into the chamber's fiery heart. Clear quartz panels in the chamber walls make it possible to observe, using cameras and lasers, how the fuel mixture burns within the chamber and how and at what temperatures pollutants are being produced. "Worldwide, there are very few test facilities with good optical access," says Meier. Another special feature of BOSS is that it is full-sized. DLR already operates combustion chambers with optical access, but these had been constructed on a smaller scale. For Rolls-Royce, these are BOSS's main advantages. "The BOSS combustion chamber is immensely important to us," says Leif Rackwitz, Combustion Chambers Project Leader for Rolls-Royce Deutschland. "It's the only lean-burn combustion chamber in which we can actually see the flame, and the fact that it's built to full scale makes it much easier for us to transfer our results to real engines. This makes it uniquely valuable."

Real operating conditions in a lean-burn combustion chamber are investigated and analysed using the High Pressure Combustion Chamber Test Stand 1, located at DLR's Cologne Headquarters. Air is heated to more than 600 degrees Celsius before being supplied to the facility. "This simulates the heating of the air in the compressor at the front of the jet engine," explains Christoph Hassa. Fuel is added to the hot air inside the combustor and the mixture is ignited. A port in the combustion chamber allows a camera probe to observe the process. "Just by looking into the chamber, we can see where the mixture is burning and whether the flame is sooty," Meier adds.

The researchers employ lasers to measure how fuel is distributed inside the lean burner. "It is particularly important to deliver the fuel in an optimal way if it is to burn efficiently," says Meier. "We look at how and where the fuel burns, where the heat required to drive the engine is released and whether there are problem areas within the combustion chamber." In addition, lasers allow the determination of temperatures throughout the chamber's interior. The extent to which the process reduces emissions is measured with a sampling probe in the test stand's exhaust.

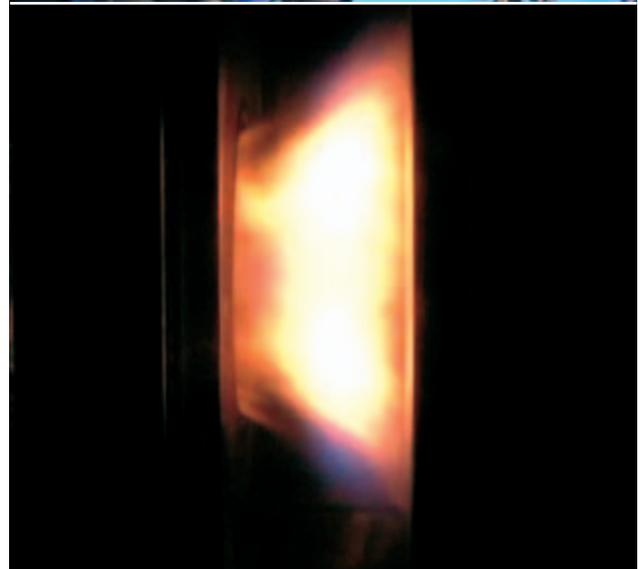
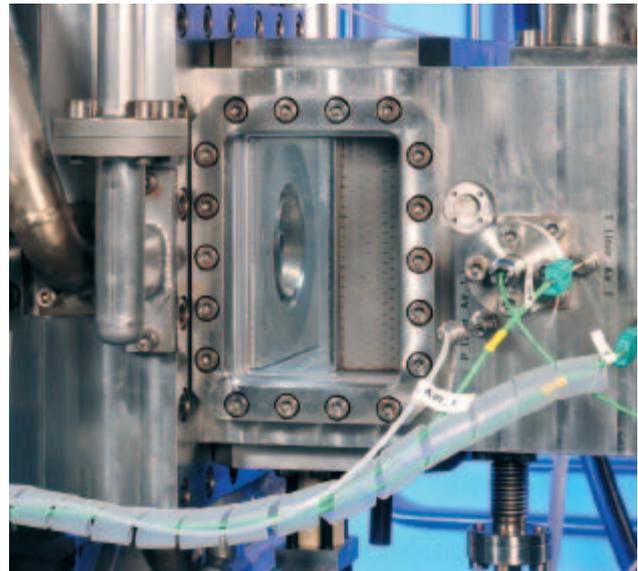
Rolls-Royce will be investigating lean-burn combustion at the High Pressure Combustion Chamber Test Stand 1 over the next three years. "The test stand has already been used in numerous German and European research projects," says Hassa. "And it has already contributed significantly to making future aviation more environment friendly." ●

#### About the author:

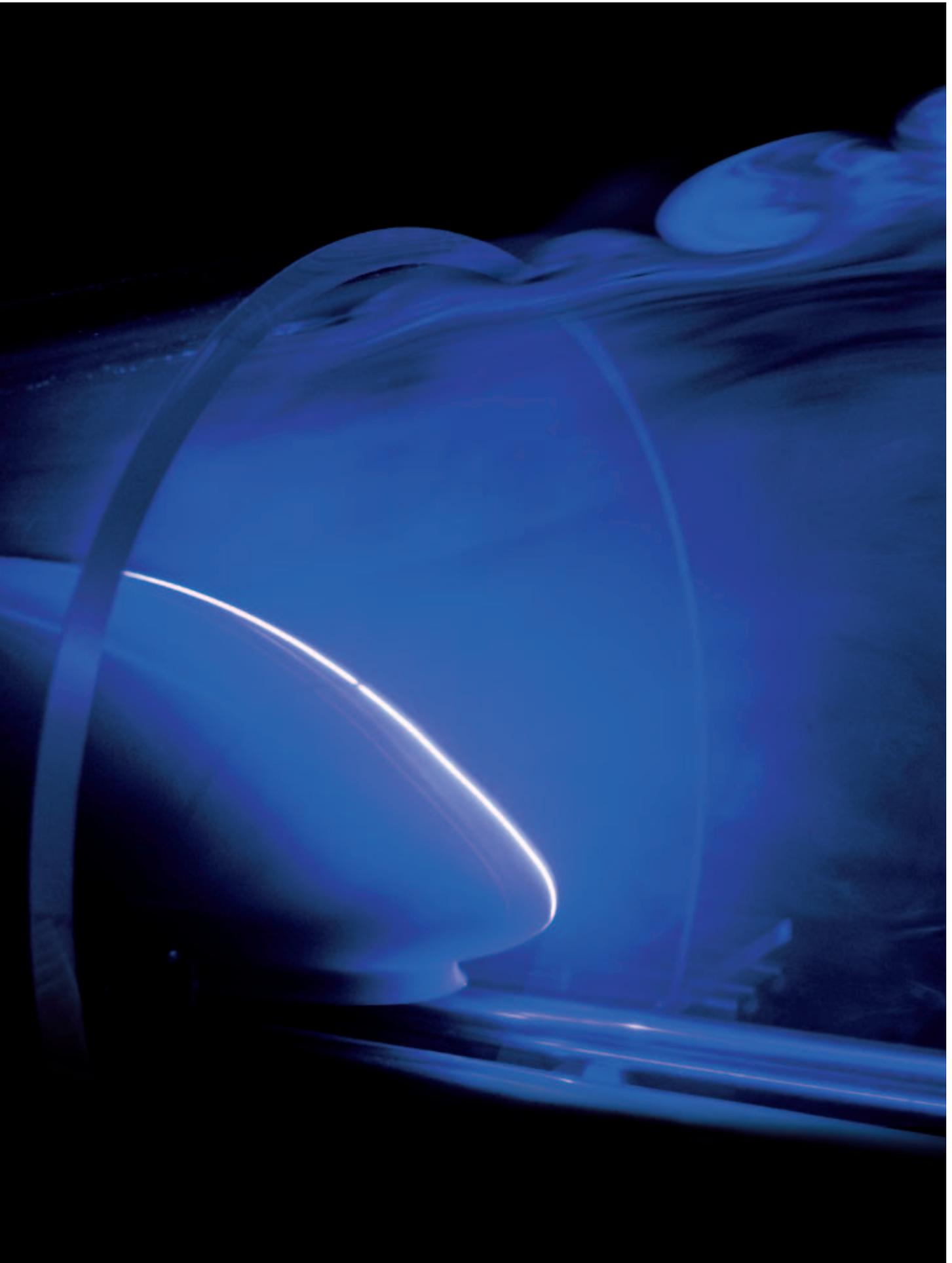
Jonathan Focke is a student of science journalism at the Technical University of Dortmund and was an intern in DLR's Corporate Communications Department from July to September 2010.

#### More information:

[www.DLR.de/AT/en](http://www.DLR.de/AT/en)



Top: the heart of the test stand – the combustion chamber with optical access. Middle: the visible flame, observed by a monitoring camera. Bottom: Ulrich Meier (left) and test engineer André Mögelin in the control room of the facility, at a safe distance from the noise, extreme temperatures and high pressures



# Flight school for trains

**It happens frequently on the motorway; when overtaking a truck in a strong crosswind, the wind delivers a powerful side force as the overtaking car drives out of the shelter provided by the truck. Sometimes, strong countermeasures are required to stay in lane. But how would a double-decker train cope when it exits a tunnel at several hundred kilometres an hour and suddenly encounters a strong gust from the side?**

## One-of-a-kind DLR facility uses a catapult to accelerate train models for high-speed testing

By Jens Wucherpfennig

### Railway vehicle aerodynamics research topics

- Energy consumption (drag) and noise emissions
- High-speed safety (crosswind sensitivity)
- Shockwave and slipstream effects through tunnels and station platforms
- Embankments (under-vehicle airflow, ballast disturbance)
- Acceptance tests for the European Railway Agency's Technical Specifications for Interoperability
- Environmental controls and onboard systems

In the new tunnel simulation facility at DLR Göttingen, researchers are using smoke and lasers to study the performance of high-speed trains in tunnels

Aerodynamic design is absolutely crucial to ensure that the next generation of taller, faster, increasingly lightweight and more efficient trains stay safe in such situations. At DLR Göttingen, two new research units are investigating the ideal aerodynamic shape for future trains. These facilities were unveiled on 8 October 2010 and include a unique tunnel simulator where scientists can study the running characteristics of train models at speeds of up to 400 kilometres per hour. More than three million Euro has been invested in the two units.

"We want to proceed towards more environment-friendly, lighter and more comfortable trains," explained the DLR Executive Board member for Transport, Ulrich Wagner, at the Göttingen launch. "We're developing the technologies for the trains of tomorrow and are demonstrating what is technically feasible."

### Entirely unique

The two new facilities are a completely unique tunnel simulator and a crosswind testing system. "Until now, there has been no single institution where the behaviour of trains travelling at very high speeds in tunnels can be investigated," explains the Head of DLR's Institute for Aerodynamics and Flow Technology, Andreas Dillmann. Employing the most up-to-date measurement technology, the research focuses on studying the aerodynamic behaviour of high-speed trains in tunnels. The point at which the train enters the tunnel is of particular importance: it enters a tunnel like the piston in an air pump, this produces a pressure wave, which can create a sound similar to that of a supersonic jet. One objective of the researchers in Göttingen is to prevent this from happening.



With the new research facilities at Göttingen, it is possible for aerodynamics researchers to simulate two critical high-speed phenomena: an effect similar to a sonic boom can occur while passing through a tunnel, and the lighter trains of the future must not tip over in crosswinds. The wind is simulated by a fan beside the track (centre right). The model trains are propelled by a catapult to about 400 kilometres per hour (centre left, lower left). The commissioning of these new facilities makes DLR "The European leader in railway aerodynamics," says Andreas Dillmann (in the image at the bottom right)

## Predicting the risks of crosswinds

High-speed trains have another problem. "At 300 kilometres per hour, significant lift is generated at the nose of a double-decker train and it could tip over in a strong crosswind, despite the train weighing hundreds of tons," explains Andreas Dillmann. This is why Göttingen also has a crosswind testing facility. Here, researchers can simulate the forces and pressures that a train experiences when subjected to such forces and they can explore ways to reduce crosswind sensitivity.

While the principle of conventional wind tunnels is based on air moving around a stationary model, this tunnel simulator is much more realistic. The model actually moves like its real-life counterpart. "This means that we avoid the systematic errors that arise in conventional wind tunnels and can create a realistic representation of the interaction between the train and the trackbed for example," explains the Project Manager for the new facilities, Sigfried Loose.

## Lessons from antiquity

In their search for an effective way to accelerate train models in the shortest possible time, DLR researchers sought help from the Romans. In ancient times, Romans would use weapons powered by torsion to fire arrows at their enemies. Otherwise known as ballistas, they would catapult arrows at around 50 metres per second. Equipped with a hydraulic pump, the DLR version achieves speeds of 100 metres per second. Two levers use cable winches to catapult a wheeled carriage carrying the model, which is built to a scale of between 1:20 and 1:100. Magnets slow the carriage after a few metres and then the model rolls along 60-metre long rails at speeds of up to 400 kilometres per hour. "The acceleration is up to 100 g," says Sigfried Loose. Lasers, high-speed cameras and pressure and temperature sensors are used to record each test run. The measurement technology is still undergoing development. The train model comes to a standstill in a bed of polystyrene spheres.

Göttingen has a long tradition of studying railways. In 1913, wind tunnel studies were carried out on trains for the Royal Prussian Railway Administration. "We've been testing trains here for a long time," says Loose.

One practical invention originating in Göttingen was used in many steam locomotives. 'Betz' smoke deflectors cleared the engine exhaust away from the driver's cab, providing clearer vision for the crew. Also, the technology for the magnetic levitation train – used today in Transrapid rail – was developed at Göttingen in the 1930s. Since the introduction of high-speed trains, aerodynamics has become all the more important. The shape of the nose for the first German high-speed train, ICE 1, was based on research performed at DLR Göttingen. The researchers apply the lessons learned from aeronautics to railway vehicles – in effect, the trains attend flight school.

The Vehicle Aerodynamics and Noise Emissions project, launched in 2001, marked the beginning of the systematic study of vehicle aerodynamics at DLR.

The tunnel simulation and crosswind testing units that have now been brought into operation supplement DLR's existing large-scale train research resources: the high-pressure wind tunnel in Göttingen and the cryogenic wind tunnel in Cologne. There is also a high-performance computing cluster for vehicle aerodynamics: the Simulation Center for Aerodynamic Research in Transportation. "This makes DLR the European leader in railway aerodynamics," says Andreas Dillmann. ●

## DLR's Next Generation Train Project:

DLR's Next Generation Train project focuses on aerodynamic features of the trains of the future. The skills of eight DLR institutes have been brought together under the aegis of DLR's Institute of Vehicle Concepts in Stuttgart. The main objective is to advance research and development for the next generation of high-speed trains. To further this aim, DLR researchers are studying how they can increase speed while halving the specific energy consumption, how to make trains quieter, safer and more comfortable, how to minimise wear and reduce life-cycle costs, how to build trains in a more cost-effective manner through modularisation and system integration, and how development and approval processes can be made more efficient.



Faster and more economical: DLR tests the train of the future in the Next Generation Train Project. The aerodynamics for this project are investigated at DLR Göttingen

### About the author:

Jens Wucherpennig is a Communication Officer at DLR's Göttingen facility.

### More information:

[www.DLR.de/en/Tunnelsimulation](http://www.DLR.de/en/Tunnelsimulation)



# Driving ahead – how will we drive tomorrow's cars?

As the German Aerospace Center, DLR is primarily associated with aeronautics and spaceflight. To make flying safer, automation has been the norm for commercial aircraft for decades. Now, similar developments for cars are underway. Drawing on its expertise in aeronautics, DLR's research on transportation systems is contributing to research and development for road transport. This is resulting in promising new developments extending automation to ground-based vehicles.

## From assisted to highly-automated vehicle control

By Frank Flemisch, Anna Schieben and Henning Mosebach

Modern aircraft are flown by autopilots and flight management systems for long periods, leaving the pilot to monitor the flight. Even when the pilot is in control, automated systems are continuously guiding him. They issue warnings about dangerous circumstances or hazardous inputs by the pilot. Yet the benefits of automation in aviation have a significant downside; operating a complex cockpit can bring new problems of its own. Aviation copes with this through intensive pilot training – an option that is only partly practical for driving.

### **What can automation offer for cars and where are the challenges?**

Aviation has chosen its way forward. Now the development of automated driving for road transport is underway too. There are already mass-produced individual assistance systems such as adaptive cruise control, which can automatically maintain vehicle separation. Autonomous driving – meaning automated, driverless vehicle operation – has already been demonstrated in simplified situations such as the Grand Challenge competition overseen by the US Defense Advanced Research Projects Agency, DARPA. However, these systems are not good enough to allow driverless operation of mass-produced cars. So how can we exploit the potential of automation for safety and convenience? How will we drive the cars of the future? How do we meet the challenge of making complex automation accessible and usable for the average driver?

No matter what the appearance of the cars of the future, their assistance functions and powerful automation will make driving easier and safer

As with aviation, the approach being taken by DLR and its industrial and research partners focuses not on replacing the human, but on a highly-automated, collaborative combination of technology and driver. The aim is a vehicle that could drive

itself, but only if the driver wants it to, and always in a way that the driver remains involved and can take over at any time. So drivers will be able to remain in control and drive along routes they enjoy; if something critical happens and they do not react in time, automation can step in to prevent a possible accident. The car could drive itself on monotonous stretches, with the driver keeping a watchful eye (and hand) on things.

Besides the numerous technical challenges, the most exciting research questions are focused on what the driver of such a vehicle should do for his part to remain sufficiently involved and to take over control safely when needed. Another interesting point is the expectations that drivers have of such a system and how the interface between the person and the automated system should be designed so as to make it simpler than an aircraft cockpit.

### What would you expect from highly automated vehicles? From user surveys to the foundations of collaborative vehicle driving

DLR researchers are investigating how drivers of the future might be able to travel in a highly automated car and what information should be displayed in the vehicle to ensure their continuous awareness of the vehicle's status. The interaction, or collaboration, between the driver and the automated vehicle is being designed in cooperation with potential users of these vehicles. To achieve this, researchers are inviting car drivers to a laboratory at DLR's Institute of Transportation Systems in Braunschweig to ask them about their expectations of such a vehicle.

This Straightforward Modular Prototyping Laboratory, or SMPLab, has been built for rapid prototyping of driver assistance and automation systems. It incorporates two small driving



With the FASCar test vehicle, DLR is testing new concepts for highly automated driving

simulators, each with a driver's seat. The simulators are fitted with a steering wheel and accelerator and brake pedals. The notable element here is that the steering wheels and pedals in both simulators are linked to each other, so that the steering wheel in one simulator can move the steering wheel in the other; the same is true of the pedals. This assembly is called a 'theatre system', because users and designers can play through situations and technologies that are not yet reality, just like in a theatre. The test subject sits in the left-hand driving simulator and a DLR researcher plays the part of the automated system in the right-hand driving simulator. Through this coupling of the steering wheels and pedals, test subjects can see and feel for themselves just what the automated system is trying to do.

While various situations are being simulated, the test subject is asked what expectations he or she has of a highly-automated vehicle; for instance: "What should the vehicle do if an obstruction suddenly appears in front of it?" The test subject can suggest what should happen by operating the steering wheel or pedals, and say whether a prompt on the display or a sound alert would be useful and, if so, in what way. A variety of driving situations are simulated in this manner. The ideas are recorded on video and in audio interviews.

To better consider the interaction between driver and vehicle, DLR researchers, working with researchers and developers at the Technical University of Munich and NASA, use a common design metaphor: the interplay between a horse and its rider, or between a horse and the driver of the carriage it is pulling. The fact that the horse can understand its environment, but is nevertheless controlled by a human, makes this an especially useful paradigm for the design of the interface between the driver and a highly automated vehicle.

When research concepts and user expectations are put together, the interaction methods are designed; the displays and acoustic and force-feedback signals are conceived, and how these forces and vibrations affect the controls is determined. This interaction is then built into software prototypes. The prototypes in turn are used to control vehicles in a highly automated manner and their performance in various driving situations is recorded. They are tested in both DLR simulators and test vehicles.

### From basic research to industrial implementation: Highly-Automated Vehicles - Intelligent Transportation HAVEit

The next stage is equally exciting: the concepts and algorithms developed in the vehicle laboratory are trialled using the DLR Institute's test vehicles. The new automation system – the highly-automated vehicle's 'horse's brain' – recognises the vehicle's surroundings via sensors, plans the optimum driving strategy relative to the available options and takes the driver through the appropriate manoeuvres. To enable this, the vehicle's sensors are linked to one another.

One essential component of this intelligent behaviour can be demonstrated in today's test vehicles. The concepts behind highly-automated driving have now flourished to a point where the development of a real product is already possible. Such systems are being developed in the European Union's Highly-Automated Vehicles - Intelligent Transportation, HAVEit project, using components which are almost ready for mass production. This activity covers both the sensors and actuators in the vehicle, which the automated system can use to intervene during a driving manoeuvre. The 'brain' here can also be manufactured using compact, mass-produced electronic control devices. These make use of software development processes that are standardised in the car industry. Employing these devices ensures that the innovative functionality of the new software will be combined with robust development processes.



The prototype of the driving assistance and automation system being tested in the dynamic driving simulator at the DLR Institute of Transportation Systems

Automated systems are tested using the DLR steer-by-wire vehicle, FASCar II. This research vehicle has no steering column and the manoeuvring commands are transmitted electronically instead, as are the positions of the accelerator and brake pedals. This allows the development of completely new interaction mechanisms between the driver and the automated system. Following extensive testing in simulators and test vehicles, the systems are currently being installed and tested in Volkswagen and Continental cars and a Volvo commercial vehicle. Highly-automated driving will be showcased in the EU's final demonstration for the Highly-Automated Vehicles - Intelligent Transportation project in 2011, using DLR's test vehicle.

So how will we drive the cars of tomorrow? We are still a long way from having solved all the research issues related to highly-automated driving. However, the research results encourage the hope that, in the future, we will be able to choose when we want to drive ourselves, that we will be supported by competent assistants when conditions are potentially risky, and that we will be able to hand boring sections of a journey over to automated systems – but without completely giving up the reins. ●

#### About the authors:

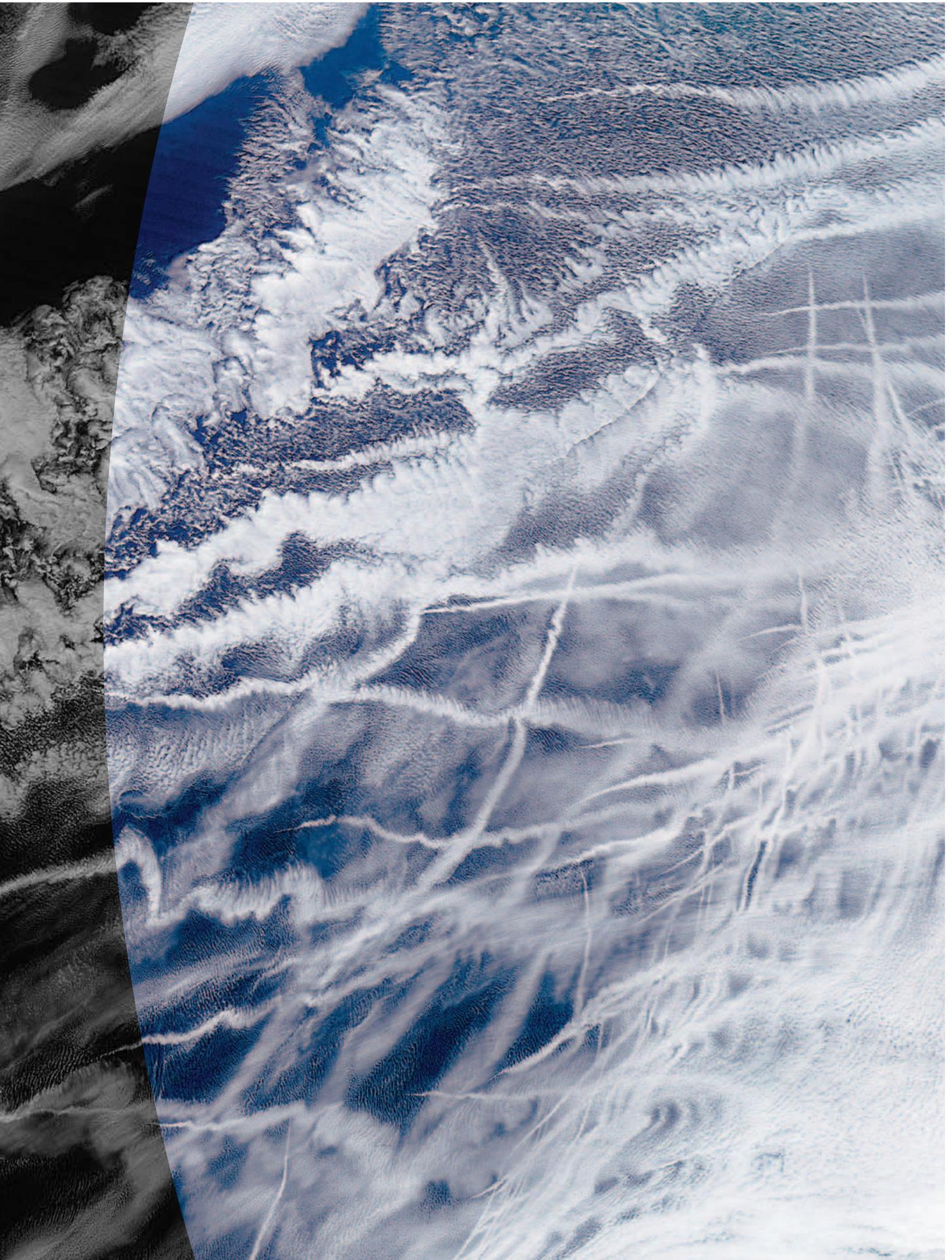
Frank Flemisch is the head of the Systems Ergonomics and Design Research Group at the DLR Institute of Transportation Systems in Braunschweig.

Anna Schieben conducts research into transitions between different degrees of automation in assisted and highly-automated vehicles.

Henning Mosebach is the head of the Test Vehicles Research Group at the Institute of Transportation Systems.

#### More information:

[www.DLR.de/fs/en](http://www.DLR.de/fs/en)



# Transport emissions: a problem in the air

The transport sector is experiencing rapid growth – but not without consequences for the climate. Transport is the single human activity with the fastest growing rate of greenhouse gas emissions. This applies particularly to the European Union, where carbon dioxide emissions and those of the other gases covered by the Kyoto protocol have shown an overall decrease, but transport emissions have increased 36.5 percent from 1990 to 2007. The increase due to air traffic is particularly large, almost doubling in this period. If this trend continues, in a decade's time, transport could be responsible for almost half the carbon dioxide equivalent emissions, including methane, nitrous oxide and other Kyoto-regulated gases. So there is ample reason to take a closer look at the contribution transport makes to climate change – hence the QUANTIFY and ATTICA projects.

## Results of the European Integrated Project QUANTIFY and the Specific Support Action ATTICA

By Robert Sausen

Transport not only emits greenhouse gases such as carbon dioxide (CO<sub>2</sub>) and nitrous oxide (N<sub>2</sub>O), it also influences the climate through a sequence of other processes that lie beyond the scope of the Kyoto Protocol. These include the emission of water vapour, a variety of ozone precursors such as nitric oxides (NO<sub>x</sub>) and particles and their precursors such as soot and sulphur compounds. Transport emissions trigger the formation of additional clouds (contrails and contrail cirrus) and modify natural clouds through aircraft-induced particles that can serve as cloud condensation nuclei. Referred to as non-CO<sub>2</sub> effects, these are of particular importance in the case of transport since its emissions frequently occur in locations and at altitudes with no other major emission sources.

Within the EU-15, the sum of all CO<sub>2</sub>-equivalent emissions decreased by 5.5 percent between the base year of 1990 and 2007, in accordance with the stipulations of the Kyoto Protocol. However, during the same period, the corresponding emissions due to transport rose by 36.5 percent. In 1990, transport contributed almost 22 percent of all EU-15 CO<sub>2</sub>-equivalent emissions, whereas by 2007 it had reached almost 32 percent. If the EU reaches its new reduction goal (minus 20 percent relative to 1990 by 2020) and transport emissions continue to increase as quickly as they have in the last two decades, the fraction due to transport will amount to about 45 percent by 2020.

Ship tracks over the Bay of Biscay,  
off the French Atlantic coast



QUANTIFY measurement campaign at the western exit of the English Channel

©Jana Moldanova,  
IVL Svenska Miljöinstitutet

Both the increasing fraction of greenhouse gas emissions which are contributed by transport and the particular climate effects associated with the sector highlighted the need for systematic quantification of transport-related contributions to climate change. This was the objective of the Integrated Project QUANTIFY, Quantifying the Climate Impact of Global and European Transport Systems, launched in March 2005 with a budget of 12.8 million Euro and 41 participating institutions from 19 countries. In parallel, through ATTICA, European Assessment of Transport Impacts on Climate Change and Ozone Depletion, assessment reports were prepared on the effects of various modes of transport on the climate and on metrics to compare the climate impacts due to different modes of transport.

The effects of transport on the composition of the atmosphere and climate are illustrated by the QUANTIFY process chain (see diagram to right). Emissions of the major modes of transport (aviation, shipping and land transport) were described by two-dimensional, or three-dimensional (including altitude for aviation) emissions inventories, along with diurnal and annual cycles. The data includes carbon dioxide ( $\text{CO}_2$ ), nitric oxides ( $\text{NO}_x$ ), soot and distances travelled by the various modes of transport. The emissions are chemically and physically processed in the near-field behind the source and then spread over larger spatial scales. As these processes are non-linear and aviation and shipping have rather high source strengths, these modes of transport warrant special consideration in this regard. For this reason, a comprehensive measurement campaign was carried out as part of QUANTIFY, using DLR's Falcon research aircraft. In this way, the effects of the processes in the near-field behind ships were determined.

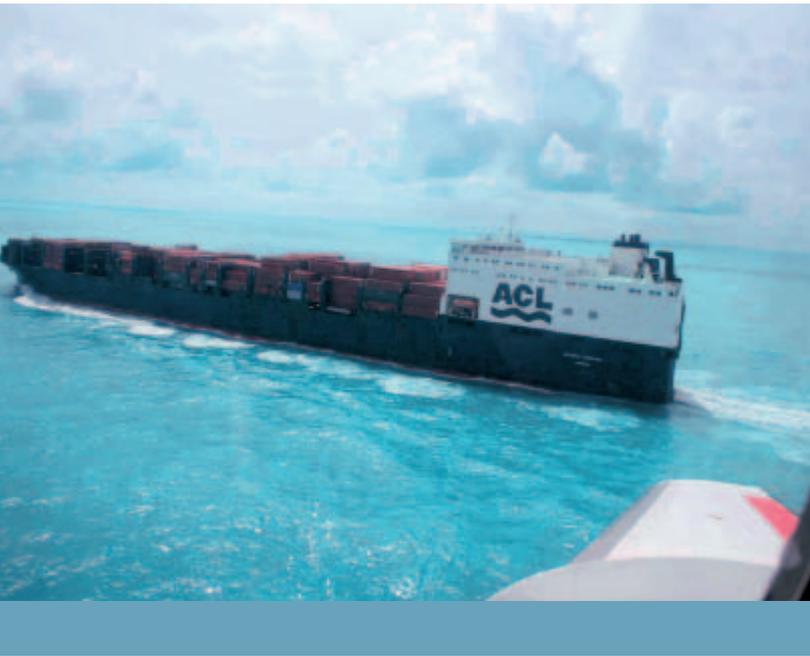
The emitted gases and particles are spread across progressively larger scales and transported until they are finally removed from the atmosphere through sink processes such as washout or dry deposition onto Earth's surface. The emissions of  $\text{NO}_x$  by transport cause catalytic ozone formation. As aviation releases its exhaust gases primarily at high altitudes (8-13 kilometres),  $\text{NO}_x$  molecules exist for a longer time than those emitted at ground level; ozone also lasts longer at this altitude. Hence, every  $\text{NO}_x$  molecule from aviation produces five times as many ozone molecules as are generated by a  $\text{NO}_x$  molecule originating from road traffic. The additional transport-induced ozone causes net warming of the climate.

As ozone is being formed, methane is destroyed by these same chemical processes. This, in turn, has a cooling effect. Exhaust from ships, which is often emitted far from any other anthropogenic source, has particular significance; here every  $\text{NO}_x$  molecule emitted by shipping reduces the atmospheric lifetime of methane by four times as much as is the case with a  $\text{NO}_x$  molecule from aviation. To summarise,  $\text{NO}_x$  from land and air transport causes warming, whereas  $\text{NO}_x$  from shipping leads to cooling.

Transport emissions also influence cloud cover. This is most visible through the formation of condensation trails (contrails) or through ship tracks. Contrail formation is triggered by water vapour emissions from aviation. In sufficiently cold and moist air, contrails can exist for a long time in the sky and spread using water vapour already present in the atmosphere. Ultimately they can develop from linear contrails into contrail cirrus, which at first sight are indistinguishable from naturally-occurring cirrus clouds. Depending on the time of day, the height of the Sun above the horizon and the background conditions, these contrails and cirrus clouds can have a warming or cooling effect. Overall, they mostly have a warming effect.

Ship tracks occur as a consequence of sulphur and soot emissions from shipping. As with contrails, ship tracks are linear-shaped clouds, but are found at a much lower altitude. These clouds generally have a cooling effect on the climate. Besides these clouds, which can be attributed directly to transport, there are also indirect influences on clouds caused by the emission of cloud condensation nuclei or their precursors, soot or sulphur compounds. Shipping is especially prominent here; its sulphur emissions in particular lead to brighter low clouds, cooling the Earth.

Apart from the processes already described here, there are more species and processes associated with transport-induced changes to Earth's radiation budget. All these modifications of the Earth's radiation budget are usually quantified using a metric known as 'radiative forcing' (measured in units of watts per square metre –  $\text{W}/\text{m}^2$ ). The expected change of the globally-averaged surface temperature is in first-order proportion to the radiative forcing. Positive radiative forcing causes warming, whereas negative forcing leads to cooling.



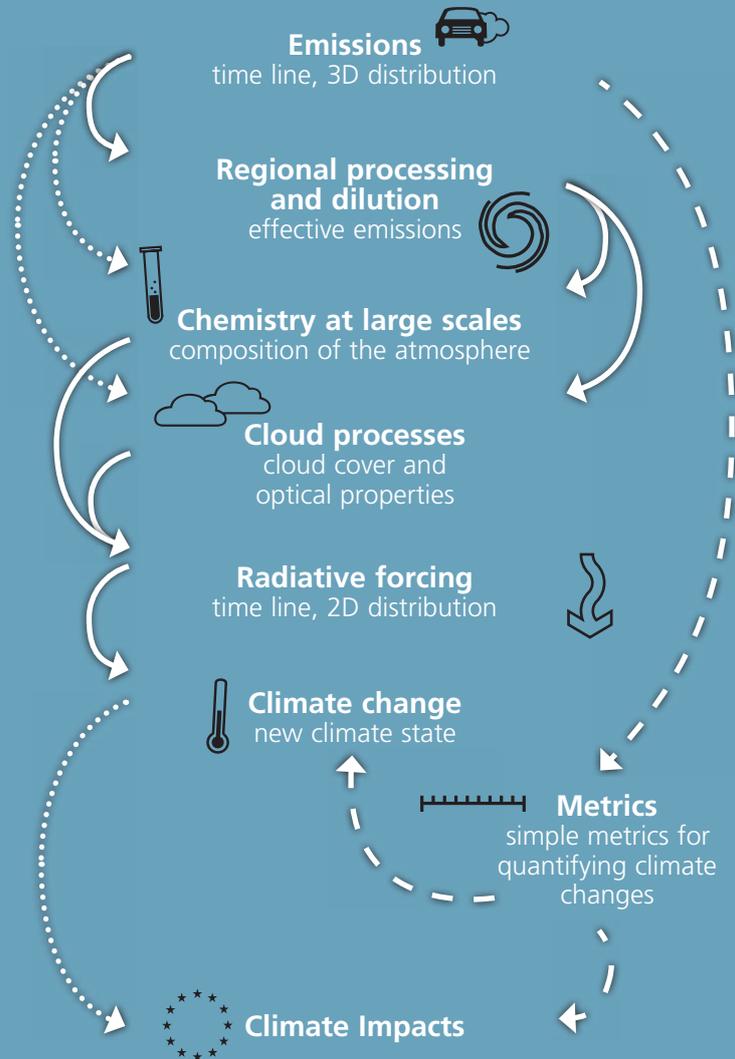
Besides the long-lived greenhouse gas carbon dioxide, the short-lived non-CO<sub>2</sub> effects are of particular importance for transport. In 2005, the total radiative forcing (based on both CO<sub>2</sub> and non-CO<sub>2</sub> effects) was 78 mW/m<sup>2</sup> (milliwatts per square metre) for aviation, -328 mW/m<sup>2</sup> for shipping, and 193 W/m<sup>2</sup> for road transport. This equates to -19.8 percent of the total anthropogenic radiative forcing for shipping, 4.7 percent for air traffic and 11.6 percent for road traffic. While air and road traffic have a warming effect, shipping cools the climate. However, the cooling effect of shipping is also associated with a massive deterioration in air quality.

When CO<sub>2</sub> emissions due to transport are considered on their own, radiative forcing in 2005 amounted to 28 mW/m<sup>2</sup> for aviation, 34 mW/m<sup>2</sup> for shipping and 171 mW/m<sup>2</sup> for road traffic – that is, 1.6 percent, 2.0 percent and 10.3 percent of total anthropogenic radiative forcing respectively.

Radiative forcing ultimately causes climate change, manifested not only as temperature change but also in other variables, such as changes in precipitation or extreme weather events. Carbon dioxide related climate forcing and forcing through non-CO<sub>2</sub> effects of transport are distinguished by their geographical distribution. This leads to different spatial patterns of temperature change.

The contribution of emissions to climate change can only be calculated with a higher accuracy using expensive numerical simulations on high-performance computers. The results obtained in sophisticated studies can be reproduced approximately with the help of measurements. In many cases, this is sufficient to quantitatively compare the various climate effects of transport with one another and with other anthropogenic climate effects. In QUANTIFY, researchers primarily investigated measurements based on temporally-integrated radiative forcing and temperature change. With the end of the project in February 2010, a quantitative comparison of the climate effects of different modes of transport is now available. ●

## QUANTIFY Process Chain



### About the author:

Robert Sausen is a climate modeller based at the DLR Institute of Atmospheric Physics. His research focuses on the effects of transport on the composition of the atmosphere and the climate. He was one of the Coordinating Lead Authors of the IPCC Special Report titled 'Aviation and the Global Atmosphere' and was appointed Lead Author of the IPCC's fifth status report.

### More information:

[www.pa.op.dlr.de/quantify](http://www.pa.op.dlr.de/quantify)  
[www.DLR.de/PA/en](http://www.DLR.de/PA/en)



# Earth: one of a kind?

There is no question that the Earth is extraordinary. It is a unique planet – in our Solar System at least. As Nobel Prize winner Ilya Prigogine once put it, Earth accommodates the most highly organised form of matter: life. Yet, given the vast number of stars and galaxies in the Universe, one has to suspect that there are other inhabited Earth-like planets. So how does such a planetary body originate and what are the conditions that make it specially capable of supporting life? And how does life in turn affect the subsequent evolution of the planet? Does life perhaps engender the conditions under which it can continue to develop optimally? These are the questions being asked by the Planetary Evolution and Life Alliance, supported by the Helmholtz Association of German Research Centres' Initiative and Networking Fund, which unites roughly 100 domestic and international scientists.

Scientists in the Helmholtz Association's Planetary Evolution and Life Alliance are on a hunt for answers to the greatest question of them all

Reflections by Tilman Spohn

So just how did Earth develop into the planet that we inhabit today, upon which there is such a diversity of life? This is not an easy question to answer, since it concerns a planet whose characteristic feature is the continuous reshaping of its surface, resulting from the dynamic processes of plate tectonics. Things are different on the Moon and Mars, the faces of which have undergone much less reshaping. Plate tectonics might even be a prerequisite for the development of life. It is responsible for the creation of mountain ranges and ocean basins, enabling biodiversity in the process, and ultimately bringing about the large-scale replenishment of nutrients for primitive forms of life. It has also given rise to conditions of thermal stability on Earth, controlling the carbon dioxide content of the atmosphere. Our Moon also extends a helping hand: it stabilises Earth's rotational axis and contributes to the stability of the climate zones. Plate tectonics, moreover, serves as an effective means of cooling Earth's interior, and therefore enables the long-term existence of its magnetic field. This magnetic field in turn protects Earth from cosmic radiation and particles in the solar wind that are hostile to life, and would erode the atmosphere.

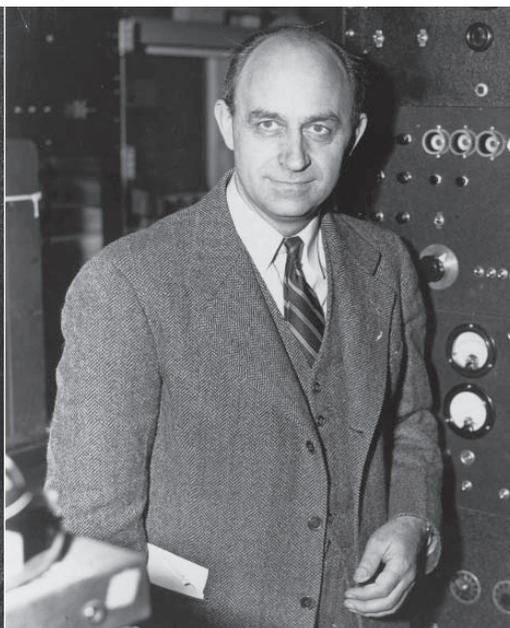
## Are we not looking properly, or are we missing the point?

The space-faring nations have set about searching for extraterrestrial life on Mars. Missions such as ExoMars and the Mars Science Laboratory, which are planned to be sent to our planetary neighbour in the coming decade, represent important milestones. A sample-return mission in the next decade could provide the breakthrough – assuming we know where and how suitable samples should be taken. Because the search for signs of life is extremely difficult as well as expensive, it requires the coordinated effort of every international partner. If this search for life should succeed, it would be of enormous significance –

The Earth-Moon system as seen by the Apollo astronauts orbiting Earth's natural satellite: two very different worlds in immediate cosmic proximity



Giordano Bruno (1548 – 1600) Italian priest and philosopher, burnt at the stake

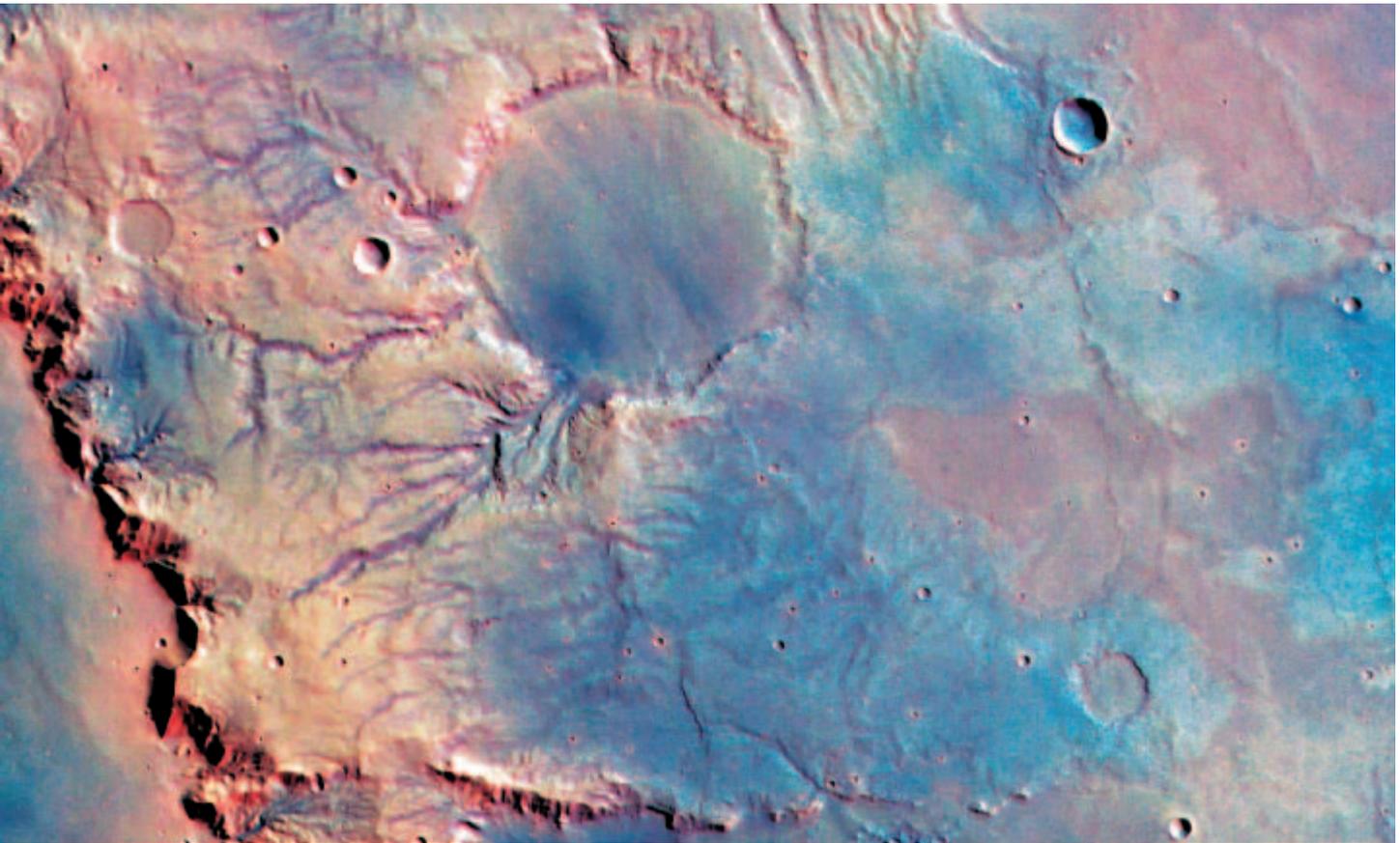


Enrico Fermi (1901 – 1954) Italian nuclear physicist, Nobel prize winner in 1938

The Helmholtz Planetary Evolution and Life Alliance is a collaboration of around 100 domestic and international scientists. It began its work in 2008. It is interdisciplinary by design and split into six subject areas:

- › Biosphere-atmosphere-surface interactions and evolution
- › Interior-atmosphere interactions, magnetic field, and planetary evolution
- › Asteroid and meteor impacts and planetary evolution
- › Geological context of life
- › Water and life under extreme conditions
- › Tools and strategies for exploration missions for planetary habitability

Each of these complex subjects is coordinated by a DLR researcher with extensive experience in the field. In total, over half the scientists involved come from DLR or the Alfred Wegener Institute of Polar and Maritime Research. Besides its leading Institute of Planetary Research, DLR has also provided members from the Institutes of Aerospace Medicine, Robotics and Mechatronics, Microwaves and Radar, and Space Systems. There are also scientists, principally from Berlin and abroad, from Max Planck Institutes and research institutes in Austria, France, the UK and USA.



False-colour image of dendritic valley systems, which suggest that water once flowed on the surface of Mars. It is assumed that a hydrological cycle existed early in the planet's history, when the atmosphere was significantly denser and warmer

reaching beyond the planetary sciences and even the natural sciences. The discovery would be the culmination of the Copernican and Darwinian revolutions and would place our Earthly existence into a larger context. Earth, which has not been the focal point of the astronomical universe since Copernicus, would also cease to be the only focal point of our cultural universe. At the end of the 16th century, Giordano Bruno was one of the first people to mention the possibility of extraterrestrial life – he paid for his ideas with his life, being burnt at the stake. And physicist Enrico Fermi (1901-1954) considered it a startling paradox that we have not yet discovered any signs of intelligent extraterrestrial life among the vast number of stars in the universe.

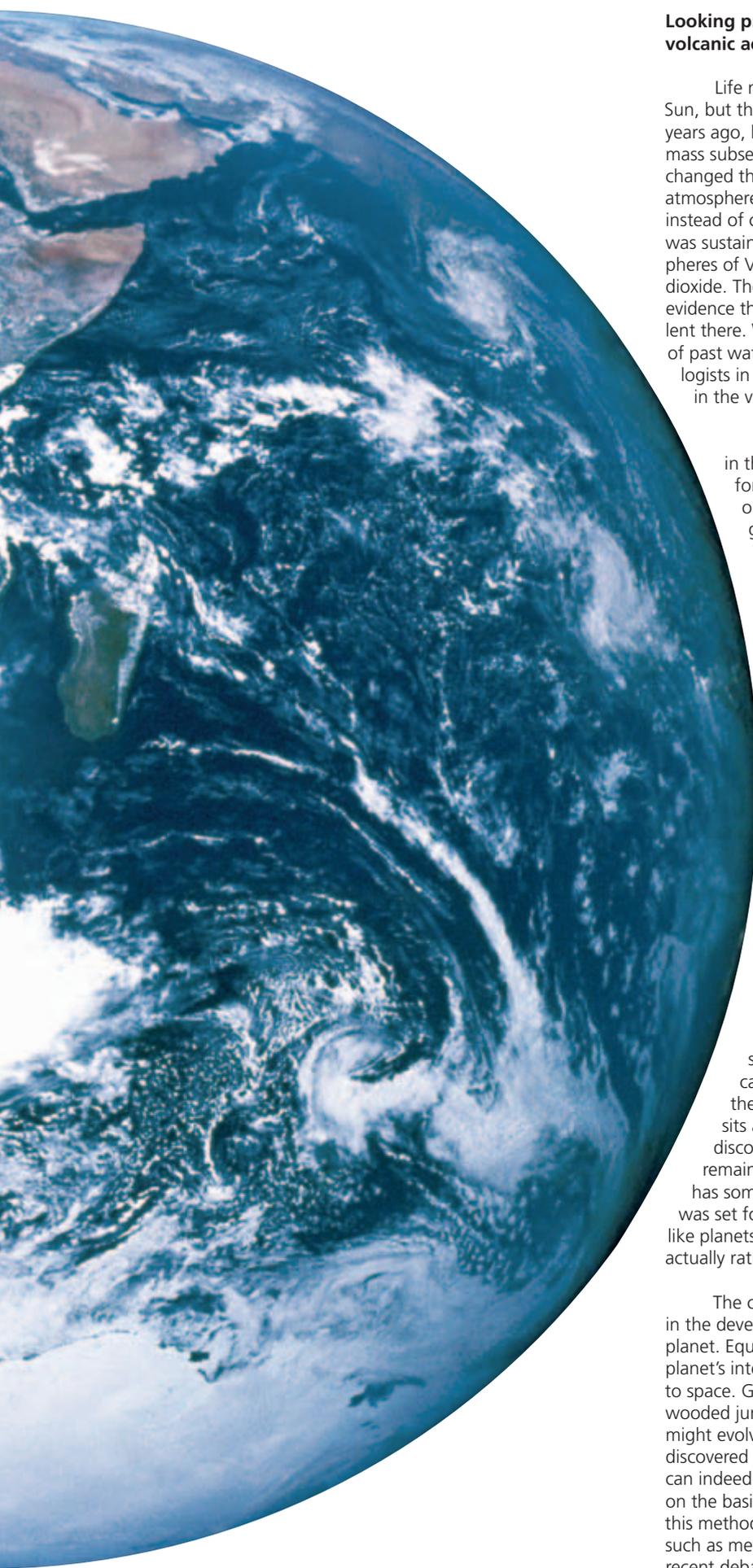
Even further-reaching than the search for life on Mars is the search for a second Earth. But how would we detect life on a far-away Earth if we are unable to go there and look for life in situ? Is there a clear signature, an ultimately convincing piece of evidence that we could detect remotely from our own distant planet?

#### **Carbon compounds and water as the essential elements**

As a starting point for our research, we are considering life that chemically resembles that on Earth. Hence we are taking carbon compounds as the essential building blocks with water as their solvent and means of transport for nutrients. Other forms of life are conceivable, based perhaps on a silicon and hydrocarbon combination, but these are not the initial focus of our considerations. Using this premise, the physical conditions for habitability – the potential of a planet to be

'liveable' – can be derived. Accordingly, the conditions on the surface of a planet or in any ecological niches should be such that water is stable under the prevailing atmospheric pressure and temperatures. It has been demonstrated that microbes can reproduce at temperatures as low as  $-20^{\circ}\text{C}$  and that under the conditions on Mars – which has just 1/150th of the atmospheric pressure on Earth – water can remain fluid down to  $-40^{\circ}\text{C}$ . This happens when certain salts lower the melting point, but bacteria can also induce the same effect. Moreover, it has been proven that biofilms – carpets or films consisting of microbes – can extract water from the slightest atmospheric humidity. A food chain for hypothetical martian microbes has also been worked out. This suggests that habitats for microorganisms might still be feasible on Mars today. They could absorb water during the day and would rest at night when temperatures drop.

Where might current or former habitats on Mars be found? Models by our Alliance indicate that the planet might have had a dense atmosphere with conditions suitable for life about 3.5 billion years ago. But how did the atmosphere thin out and end up in its current condition? This is still a riddle. Photogeological assessment of images of the martian surface taken with the High Resolution Stereo Camera operated by DLR on the Mars Express spacecraft tells a seemingly inconsistent story. Although it confirms that there were lakes and rivers on early Mars, the geological evidence also indicates an overall arid, desert-like climate with limited amounts of precipitation. At that time, Mars was more like the cold dry regions of today's Earth, rather than the temperate zones. But volcanic intrusions may have melted ground ice to form local lakes and rivers.



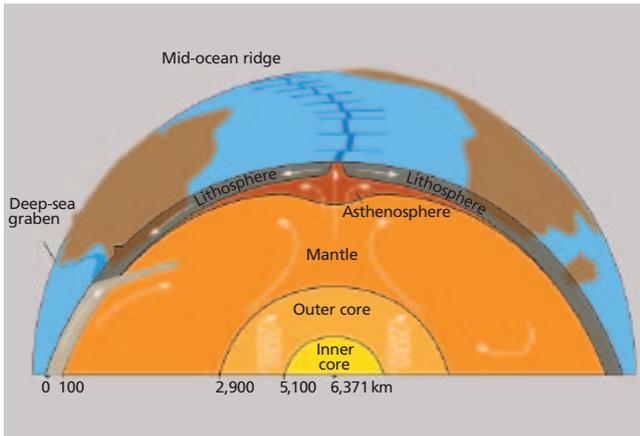
### Looking primarily in martian areas with water ice and volcanic activity

Life needs energy. On Earth, this comes mainly from the Sun, but this was not always the case. Between 2.5 and 3 billion years ago, living organisms 'invented' photosynthesis. The biomass subsequently expanded enormously and permanently changed the composition of Earth's atmosphere. At present, our atmosphere is characterised primarily by oxygen and nitrogen instead of carbon dioxide. Before photosynthesis, the biosphere was sustained mainly by volcanic heat. Even today, the atmospheres of Venus and Mars are primarily composed of carbon dioxide. The current composition of the martian atmosphere is evidence that photosynthesis never became particularly prevalent there. We should look for fossilised life on Mars where signs of past water and volcanic intrusions are to be found. The geologists in the Alliance have succeeded in identifying such areas in the vicinity of the Tharsis and Elysium volcanic regions.

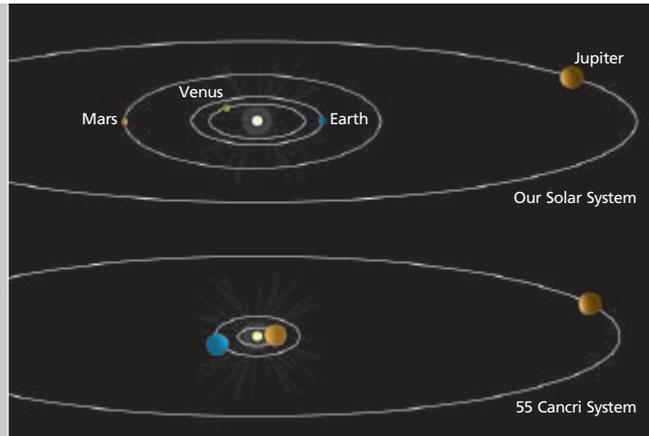
But how does a planet that can support life emerge in the first place? The Alliance's studies modelling the formation of Earth-like planets in the habitable zone of our Solar System demonstrate that the presence of the giant planets Jupiter and Saturn is highly significant. The habitable zone stretches from Venus to Mars. The formation of the relatively smaller terrestrial planets within this zone depends on the positions of the two gas giants and how their orbital paths change over time. This has significance for the question of how likely Earth-like planets are in other solar systems, although this factor is far from being entirely understood.

Within the planetary systems discovered to date around other stars, there are gas giants at locations where we find terrestrial planets in our own Solar System, orbiting at distances of less than two astronomical units (an astronomical unit is the average distance of Earth from the Sun, or about 150 million kilometres). Until now, we have not been able to find a second Earth; although in 2010, after 10 years of observation, a super Earth – a planet a few times more massive than our own Earth – orbiting its star Gliese 581 at a distance likely within the system's habitable zone, has been announced. However, this discovery still needs to be confirmed. More definitive discoveries of super Earths and perhaps even an Earth-sized planet can be expected from NASA's Kepler mission. Similarly, the European Space Agency is planning Planetary transits and oscillations of stars, PLATO, a mission capable of discovering Earth-like planets. Nevertheless, the question remains as to whether Fermi's paradox, alluded to earlier, has something to do with the fact that an unusual course was set for our Solar System at its foundation. Perhaps Earth-like planets at the optimum distance from their parent star are actually rather rare.

The climate and the availability of water play critical roles in the development of conditions friendly to life on a terrestrial planet. Equally significant is the discharge of gases from the planet's interior into the atmosphere and the loss of these gases to space. Generic models of desert planets, ocean planets and wooded jungle planets raise the question of how their climates might evolve and whether a hypothetical jungle planet could be discovered spectroscopically. It appears that these model planets can indeed be distinguished spectroscopically from one another on the basis of the chemistry of their atmospheres. Even then, this method will not necessarily indicate life, as candidate gases such as methane or ozone can also occur abiologically. The very recent debate concerning the discovery by Mars Express of



There are numerous exchange mechanisms between the interior of a planet and its surface that turn out to be fundamental to the existence of life, illustrated here with the Atlantic ocean as an example



Grafiken: © DLR (RPF)

The majority of the almost 500 exoplanets discovered to date are gas giants similar to Jupiter in nature, but unlike it they often orbit close to their stars, such as in the 55 Cancri double star system

methane in the atmosphere above several volcanic regions of the Red Planet serves as a timely reminder of this fact.

### Exchange processes with planet's interior play a key role

The atmospheres of planets are linked to their interiors. Exchange from the interior to the exterior occurs through volcanic outgassing, which plays an important role in the long-term carbon cycle. On Earth, plate tectonics enables recycling, whereby carbon dioxide locked up in sedimentary rocks can be returned to the interior. This happens in subduction zones, where the tectonic plates that make up the surface of our Earth descend into the planet's interior as if on a gigantic conveyor belt that propels the tectonic plates of the lithosphere around. Microbial life forms act as a catalyst here: they lock carbon dioxide up in sedimentary basins, enabling this recycling process to continue.

Plate tectonics is widely regarded as a prerequisite for highly-developed forms of life. Hence it is an important subject for the Alliance. Model calculations on the stability of plate tectonics highlight the parameters on which plate tectonics depends. To what extent the mass or size of the planet is relevant is not yet clear. Perhaps Earth has exactly the right proportions. A planetary magnetic field also appears to be important for highly-developed forms of life. It is evident that plate tectonics can provide a stable magnetic field. However, the question as to what role the mass of the planet plays for the generation of a magnetic field in relation to the pressure in its interior has yet to be answered conclusively. And when one considers that the Moon stabilises Earth's rotational axis by reducing wobble and also helps guarantee temperate climate zones, the odds of there being a second Earth seem rather low. Jupiter-like planets need to have cleared the habitable zone so that this life-friendly zone can be created in the first place. The size of the planet needs to have 'permitted' plate tectonics and a magnetic field, and the conditions allowing it to grow into a planet must have provided it with a large moon as well.

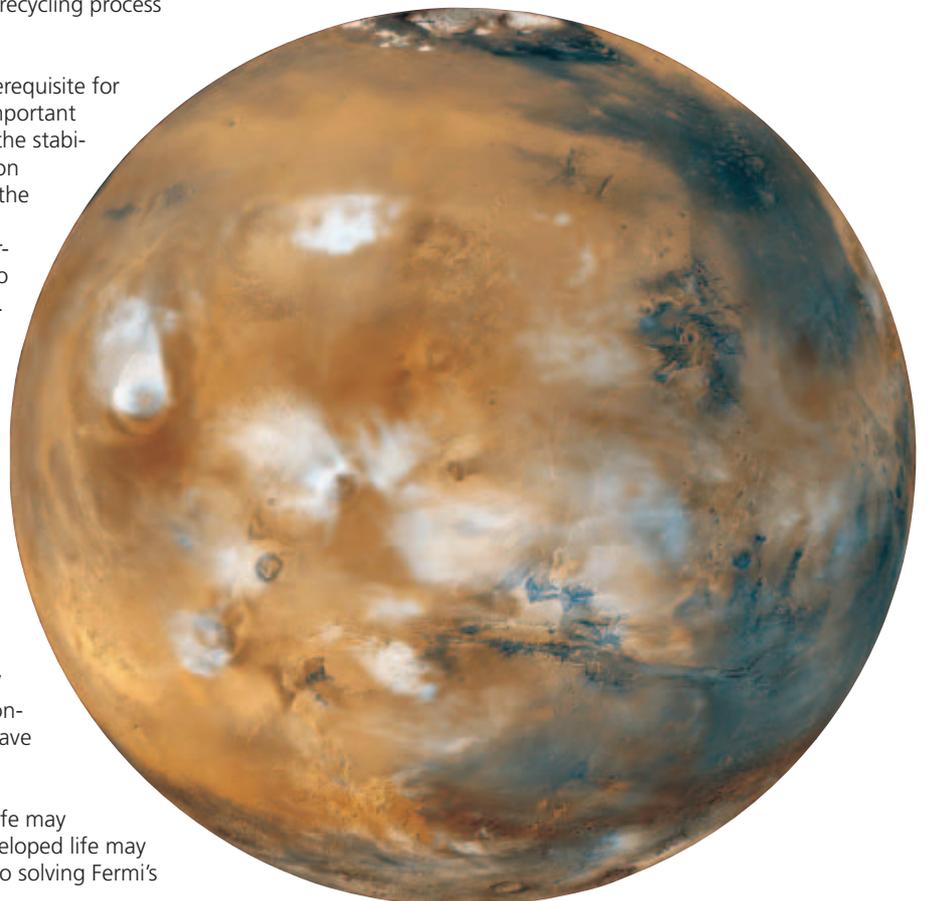
The perspective that emerges? Primitive life may potentially be distributed far and wide, but developed life may be very rare. Perhaps this realisation is the key to solving Fermi's paradox. ●

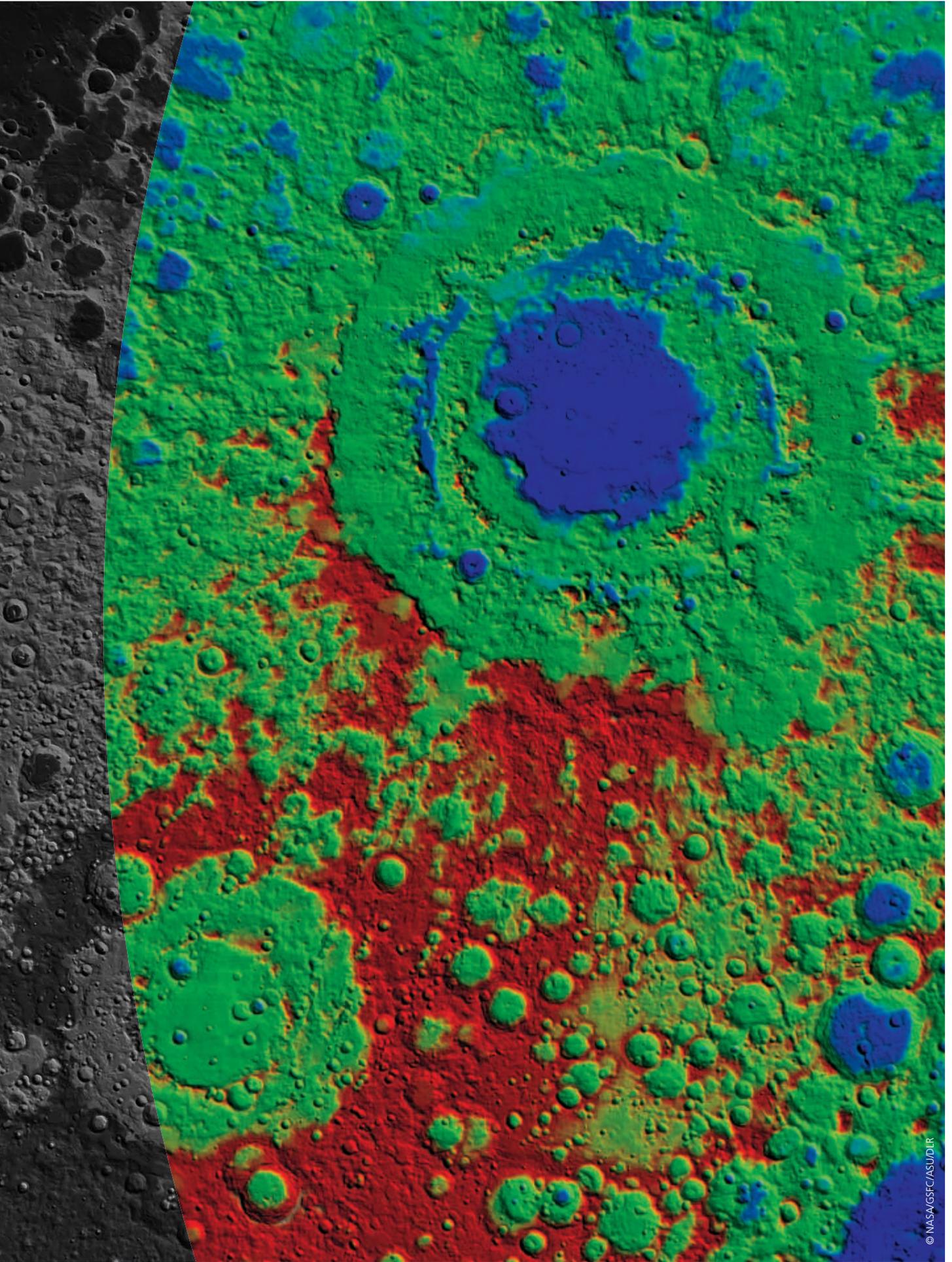
### About the author:

Tilman Spohn is a geophysicist and heads the Berlin-based DLR Institute of Planetary Research. He is also the Head of the interdisciplinary Helmholtz Planetary Evolution and Life Alliance formed in 2008, and lectures in Physical Planetology at the Westphalian Wilhelms' University of Münster.

### More information:

[www.DLR.de/PF/en](http://www.DLR.de/PF/en)





# Moon mapper

The Moon, situated 385,000 kilometres from Earth, is our nearest planetary neighbour. That puts it close enough to be seen clearly with the naked eye, and for astronauts to set foot on it. "And yet we still know relatively little about this planetary body," says Jürgen Oberst, someone who knows the Moon like the back of his hand. The 55-year old geophysicist heads the Planetary Geodesy Department of DLR's Institute of Planetary Research in Berlin-Adlershof, and teaches at the Technical University of Berlin. Oberst and his colleagues are charting not the Earth, but the other planetary bodies of our Solar System. In a conversation with Elisabeth Mittelbach, Space Editor in the DLR Corporate Communications Department, the scientist talks about his participation in recent lunar missions: Japan's 'Kaguya' probe (officially known as SELENE), as well as NASA's Lunar Reconnaissance Orbiter, LRO, which was launched in 2009.



Jürgen Oberst is a geophysicist and heads the Department for Planetary Geodesy at the Berlin-based DLR Institute of Planetary Research. He is also a lecturer at the Technical University of Berlin. He and his colleagues are studying the planetary bodies of the Solar System. Oberst was the only German researcher participating in the Japanese lunar mission SELENE.

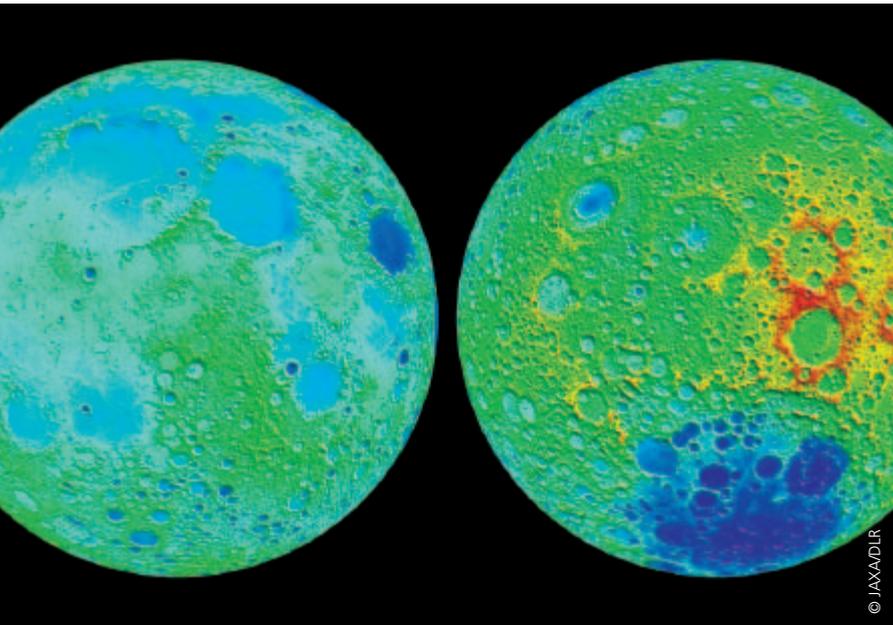
## DLR planetary researcher Jürgen Oberst is charting the lunar surface

Interview by Elisabeth Mittelbach

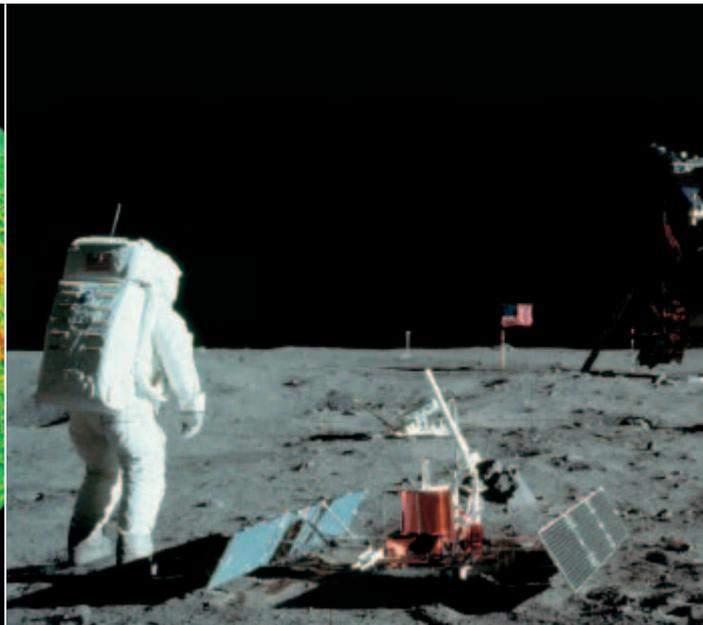
The 3.8-billion-year old, 900-kilometre wide Mare Orientale, located on the eastern stretches of the far-side of the Moon is a typical example of an impact basin. Its centre is surrounded by several concentric mountain ranges. The low-lying areas between the mountains and the centre of the crater first became filled with dark lava millions of years after the violent impact that formed it. The other circular structure is the Hertzsprung basin; north is to the left

**From 2007 to 2009, you were the only German scientist involved in the Japanese Kaguya lunar mission, and are now working with other German colleagues on NASA's Lunar Reconnaissance Orbiter. How did you get into such an unusual field?**

I have maintained personal contacts at JAXA, the Japanese Space Agency, since a research posting there in 2001. At that time I got to know Japanese scientists who were working on Moon and Mars projects – just as we are doing at DLR in Berlin. When in 2003 it was announced that Japan would be launching Kaguya, my colleagues in Tokyo thought that I might be interested. The Scientific Director, Manabu Kato, came to Berlin at my invitation and we spoke about the new mission. It also helped that DLR is regularly in contact with JAXA for strategic discussions in which collaborative projects play an important role.



The topography of the Moon based on data obtained by Kaguya's (SELENE) Laser Altimeter; the near side of the Moon (left) shows several large impact craters. At first glance, it appears that the far-side (right) has only small impact craters. In fact, the South Pole-Aitken Basin – at 2500 kilometres in diameter – is the largest impact crater in our Solar System



Most of our knowledge about the Moon comes from the Apollo era. During the Apollo Missions (Apollo 11 in this image), the astronauts left a number of instruments on the lunar surface including a radio station, seismograph and laser reflectors, with which distance and position measurements have been carried out for decades

As for NASA's Lunar Reconnaissance Orbiter, LRO, our DLR team made an official application to participate. We had to submit an extensive application in which we stated our objectives, how we wanted to achieve them and the results we expected. Our application was approved, and we're now working with a team of collaborators on the mission.

#### What was your job description with Kaguya and what is it now with LRO?

In my Department at the Institute of Planetary Research we are primarily concerned with planetary surveys, or geodesy. For instance, we process information from the High Resolution Stereo Camera on the European Mars Express spacecraft, and the Imaging Science Subsystem on NASA's Cassini spacecraft, and turn these into maps. The objective of Kaguya was to explore the Moon, both its surface and interior structure. We were looking specifically for indications of the origin and early development of the Moon. Along with topographical data, we wanted to access new images of the Moon, which we could use to make more accurate maps of the lunar surface. I was in the Laser Altimeter team, which was concerned with obtaining precise information on surface topography.

NASA's LRO mission is going a step further. The instruments on board are technically more advanced. LRO has already achieved significantly greater coverage than Kaguya and is scheduled to run for at least another three years. My team is concerned with evaluating the stereo image data. For example, we look at the Apollo landing sites and develop high-resolution

models of the terrain. While the Kaguya camera had a resolution of 10 metres, the LRO camera resolves half-metre details. We can clearly see the tracks left by the lunar rover and the instruments left behind by the astronauts.

#### Why are the Apollo landing sites such important sources of data?

For cartographers, the landing sites are important reference points, since we know their coordinates exactly. For example, the reflectors of Apollo 11, 14 and 15 are still there, and we can pinpoint them from Earth with lasers. Our speciality is geometrically-accurate mapping, in which each image element is at its proper place. The rotation of the Moon and its equator are defined, now we have to decide exactly where the enormous images we get from LRO must be fitted in. We started the job with SELENE, and we're continuing it with LRO. It's often like putting a jigsaw puzzle together. The Earth has GPS for precise location, on other planets we use planetary geodata for this purpose. The end product is topographical maps. And they are essential for future lunar missions of course.

#### And what do your altitude models tell us about the origin of the Moon?

Once we know the topography, we can calculate how much shadow and light a given location receives in different seasons, and this affects the surface temperature. You can determine the inclination of the terrain precisely or, for instance, calculate the thickness of solidified lava streams, which in turn



The laser at the NASA Goddard Geophysical and Astronomical Observatory in Greenbelt, Maryland. Satellite orbits can be followed with the laser, as was recently done with the orbit of the Lunar Reconnaissance Orbiter. It is also used to measure the position of the Moon from Earth. For this, the laser is aimed at reflectors left on three Apollo landing sites and the time taken for the laser light to return is measured precisely. The Moon moves away from Earth every year by the width of a fingernail

allows you to infer the past volcanic activity and thermal history of the Moon. Impact craters also yield a lot of information about the history of the Moon. This is why LRO represents an important milestone in lunar exploration. The topography of the Moon reveals enormous dynamics, so the Moon experienced violent deformations in its youth. Although it never experienced any Earth-like geological processes where we see mountains lifted up due to movements in the interior, the distribution processes of large impacts during the first billion years of lunar history have led to enormous altitude variations on the Moon. The highest and lowest points on the lunar surface are not even 1000 kilometres apart, and yet their difference in altitude is 19,000 metres. ●

**More information:**  
[www.DLR.de/pf/en](http://www.DLR.de/pf/en)  
[www.jaxa.jp/index\\_e.html](http://www.jaxa.jp/index_e.html)  
[www.nasa.gov/lro](http://www.nasa.gov/lro)

## Japan's SELENE: two years in lunar orbit

The Japanese spacecraft SELENE (SELEnological and ENgineering Explorer) was launched on 14 September 2007 from the Tanegashima Space Center, and orbited the Moon for a little under two years. The mission concluded on 20 June 2009 with a controlled crash into the lunar South Pole. SELENE, also known as Kaguya after a princess from Japanese fairy tales, was more than just a scientific success. NASA's Apollo missions having been terminated in 1972, this was the first time an Asian space agency successfully launched an independent lunar mission. The mission enabled scientists to determine the gravitational field of the far-side of the Moon for the first time. The spacecraft operated most of its experiments at an orbital altitude of 80 to 123 kilometres, and then at the end of its mission it was manoeuvred to roughly 10 km above the lunar surface before its controlled crash took place. Another achievement of SELENE is that it was able to map the entire lunar surface with its Laser Altimeter. DLR participated in this project with co-investigator Jürgen Oberst and his team.

## NASA's LRO: high resolution lunar mapping

The Lunar Reconnaissance Orbiter, LRO, is a NASA project. The spacecraft was launched on 28 June 2009 from Cape Canaveral together with the Lunar CRater Observation and Sensing Satellite, LCROSS. The mission is designed primarily to map the lunar surface at a high resolution and to measure the intensity of cosmic radiation across the Moon. The orbiter is in a relatively low polar orbit at an altitude of 50 kilometres. Its high-resolution images include pictures of the Apollo landing sites (see interview). In all, the Lunar Reconnaissance Orbiter carries six instruments. DLR planetary researcher Jürgen Oberst and Harald Hiesinger, Professor for Planetology at the University of Münster, are the only German scientists working as co-investigators on the LRO mission.

# 25 years of the DLR Planetary Image Facility

Pictures make concepts and discoveries so much clearer – we understand things better when we see them. Cameras on planetary probes, our most distant eyes in space, therefore play a very important role in missions exploring the Solar System, alongside equally crucial physical experiments. Suddenly, the opaque, constantly swirling layers of clouds covering Venus are rendered transparent, we can survey Mercury's cratered terrain from up close, examine the vast canyons and dormant volcanoes of Mars, and even fly through Saturn's rings.

## The entire Solar System packed into 200 square metres

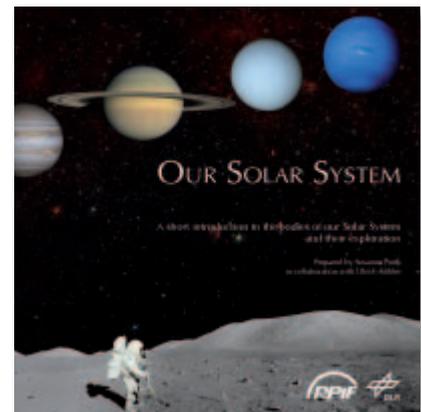
By Ralf Jaumann and Susanne Pieth

With successful planetary missions underway throughout the Solar System, public interest in the incredibly beautiful and awe-inspiring images they send back is almost endless. An increasing number of media outlets as well as educational institutions and individuals seek out these images for teaching or publication. Within the US, NASA has responded to this demand by setting up a number of regional image libraries and data centres that handle these requests quickly and efficiently. This initiative helps the Agency's efforts to enable the general public to participate in the adventure of space exploration; and it is not restricted to the US alone.

A system of image libraries, called Regional Planetary Image Facilities, was also set up beyond US borders. Through an agreement with DLR, the German Regional Planetary Image Facility was established in autumn 1985 at the Department of Planetary Exploration in the Institute of Optoelectronics at Oberpfaffenhofen. When the Department, headed at the time by Gerhard Neukum, moved to Berlin-Adlershof in the early 1990s, the Facility moved with it, and is now celebrating its 25th anniversary at the Institute of Planetary Research. The Facility consists of a 200-square-metre area divided into four large rooms, serving the entire German-speaking world, as well as meeting requests from other continents. The images come mainly from American, but also European, and Soviet or Russian space missions.

The most recent highlights are images returned by the DLR-operated High Resolution Stereo Camera aboard ESA's Mars Express spacecraft. The library's other treasures include maps and global atlases of all Solar System planets and almost all their larger moons, as well as maps of all asteroids that have been visited by spacecraft. There are also complete sets of the images returned by the Viking missions to Mars and, most notable historically, from the Lunar Orbiters that mapped the Moon to prepare the way for the Apollo programme. For the International Year of Astronomy 2009, the now defunct gasometer in Oberhausen was decorated with images from the Facility for the DLR exhibition 'Out of this World – Wonders of the Solar System'. Almost one million people have been able to view these scientifically important and exquisite images and there is also very close exchange of ideas with, and support for, teaching programmes for the DLR\_School\_Lab and DLR's youth portal, DLR\_next.

Today, there are 17 Regional Planetary Image Facilities around the world, nine in the USA, five in Europe and one each in Canada, Japan and Israel. The individual image libraries are connected through NASA's Planetary Data System and offer extensive research functions using its databases. However, despite the fact that everything seems to be online these days, there are tasks that can only be accomplished in person, rather than remotely. If the Berlin Facility does not have a sought-after image, then the request can be sent to its sister site at the Lunar and Planetary Institute in Texas. ●



The eternal appeal of the planets and moons of our Solar System inspired the researchers at the DLR Institute of Planetary Research to publish an easy-to-understand 80-page brochure called 'Our Solar System' – an ideal compendium of our knowledge of the Solar System. This brochure can be ordered in hard copy (pdf form: [www.DLR.de/rpif-orderform](http://www.DLR.de/rpif-orderform)) and is also available online for free in high resolution ([www.DLR.de/rpif-oursolarsystem\\_highres](http://www.DLR.de/rpif-oursolarsystem_highres)) and web quality ([www.DLR.de/rpif-oursolarsystem\\_web](http://www.DLR.de/rpif-oursolarsystem_web))

### About the authors:

Ralf Jaumann is Deputy Director of the DLR Institute of Planetary Research and Director of Germany's Regional Planetary Image Facility. Susanne Pieth manages the Facility.



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Outreach is as important an activity for the Planetary Image Facility as archiving and research. This aspect includes lectures for students, as well as games and quizzes for children during the 'Long night of the sciences' in Berlin

## About DLR

DLR, the German Aerospace Center, is Germany's national research centre for aeronautics and space. Its extensive research and development work in aeronautics, space, transport and energy is integrated into national and international cooperative ventures. As Germany's Space Agency, the German Federal Government has given DLR the responsibility for planning and implementation of the German space programme, as well as international representation of Germany's interests in this field.

Approximately 6700 people work for DLR. The Center has 33 institutes and facilities at 13 locations in Germany: Cologne (Headquarters), Berlin, Bonn, Braunschweig, Bremen, Göttingen, Hamburg, Lampoldshausen, Neustrelitz, Oberpfaffenhofen, Stuttgart, Trauen and Weilheim. DLR also has offices in Brussels, Paris and Washington D.C.

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DLR Corporate Communications  
Porz-Wahnheide, Linder Höhe,  
D 51147 Cologne  
Telephone: +49 (0) 2203 601 2116  
Fax: +49 (0) 2203 601 3249  
Email: [kommunikation@dlr.de](mailto:kommunikation@dlr.de)  
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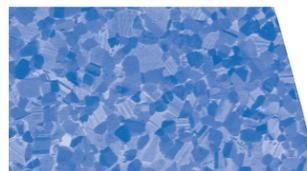
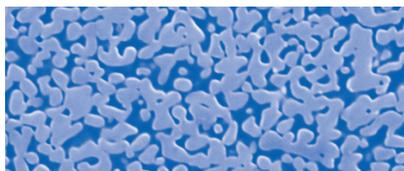
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