# DLRmagazine

of DLR, the German Aerospace Center · No. 169 · December 2021

# JUMPING ON BOARD THE DIGITAL TRANSFORMATION

## PREPARING RAIL TRANSPORT FOR THE FUTURE

More topics

- WHAT'S UP?
  Everything that needs to be considered in efforts towards climate-neutral aviation
- AROUND THE WORLD WITH 100 EXPERIMENTS
  An ambitious research programme on board the ISS

**About DLR**

DLR is the Federal Republic of Germany's research centre for aeronautics and space. We conduct research and development activities in the fields of aeronautics, space, energy, transport, security and digitalisation. The German Space Agency at DLR plans and implements the national space programme on behalf of the federal government. Two DLR project management agencies oversee funding programmes and support knowledge transfer.

Climate, mobility and technology are changing globally. DLR uses the expertise of its 55 research institutes and facilities to develop solutions to these challenges. Our 10,000 employees share a mission – to explore Earth and space and develop technologies for a sustainable future. In doing so, DLR contributes to strengthening Germany's position as a prime location for research and industry.

**Imprint**

DLRmaGazine – the magazine of the German Aerospace Center

Publisher: DLR German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt e. V.)

Editorial staff: Nils Birschmann (Legally responsible for editorial content), Julia Heil, Elke Heinemann (Editorial Management), Karin Ranero Celius (English-language editor, EJR-Quartz BV)

DLR Department of Communications and Media Relations
Linder Höhe, D 51147 Cologne
Phone + 49 2203 601-2116
E-mail info-DLR@dlr.de
Web DLR.de/en
Twitter @DLR_en

Printing: AZ Druck und Datentechnik GmbH, 87437 Kempten
Design: CD Werbeagentur, Burgstraße 17, 53842 Troisdorf, www.cdonline.de

ISSN 2190-0108

Online:
**DLR.de/dlr-magazine**

Order online:
**DLR.de/magazine-sub**



Climate neutral
Print product
ClimatePartner.com/53106-2111-1001

MIX
Paper from responsible sources
FSC® C008457
www.fsc.org

Printed on recycled, chlorine-free bleached paper.

Deutsches Zentrum
für Luft- und Raumfahrt
German Aerospace Center

Supported by:
Federal Ministry for Economic Affairs and Energy
on the basis of a decision by the German Bundestag

# EDITORIAL

## NEW FORMS OF EXCHANGE

Whether it's the EXPO 2020, the 60th anniversary of DLR's site in Stuttgart or the annual astro seminar, where interested parties will be given the opportunity to learn more about black holes in 2022, DLR and its scientists are involved in a wide variety of events – both online and physically. While last year's events were held exclusively virtually due to the Coronavirus pandemic, it is now possible – with the appropriate measures and restrictions – to hold events in person again.

DLR's exhibition stand at the ITS Congress 2021

Virtual exhibition stands were created where guests could navigate through picture galleries and lecture rooms. In addition, with the increasing relaxation of measures, so-called hybrid events were held. This kind of event gives speakers unable to travel to the event the opportunity to convey their content via livestream, while interested parties unable to attend can access the lectures at a later stage in the online archive. The format has also proven its worth from a sustainability standpoint, as it means saving on the travel and waste that would otherwise have been generated when setting up and dismantling the exhibition stands. Nevertheless, an exchange in a virtual conference room can hardly replace a real conversation. Even if face-to-face events become the norm once again, hybrid formats are unlikely to disappear completely, as their advantages are too good to be ignored. At the same time, DLR is constantly working on innovative event formats, in order to set the course for the way we will exchange in the future.

All events by and with DLR can be found at **event.DLR.de/en.**


Presenting DLR's new platform for event planning

**Dear reader,**

State-of-the-art, climate-friendly rail transport has an important role to play in achieving the climate targets in the transport sector. Such a system should be sustainable not only from an environmental and social standpoint, but also in economic terms. Automation, new communications technologies and standards, the use of machine learning and artificial intelligence all have the potential to make rail transport much more attractive, as well as competitive.

DLR scientists are working on new ideas, concepts and technologies to make rail transport fit for the future. However, the impetus for change is not limited to the rail sector: in aviation, aspirations for climate-neutral flight necessitate a review of propulsion systems and route planning. To this end, DLR has published a new aeronautics strategy aimed at decoupling the growth of the aviation industry from its environmental impact. Hydrogen offers scope for reducing the emission of environmentally harmful gases. Yet is it possible to run everything on hydrogen? Would it even make sense to do so? In this issue, we get to the heart of this matter through an interview with a climate scientist, an aeronautical propulsion engineer and an energy researcher.

Other topics in this December issue include the Cosmic Kiss mission of German ESA astronaut Matthias Maurer, who has begun his work on the International Space Station ISS following several launch delays; DLR technologies related to disaster response that are being developed in tandem with an aid organisation; and an experiment in the former TITAN pressure chamber in which deep sea divers reached a depth of more than 600 metres – without ever going underwater.

We hope you enjoy this issue.

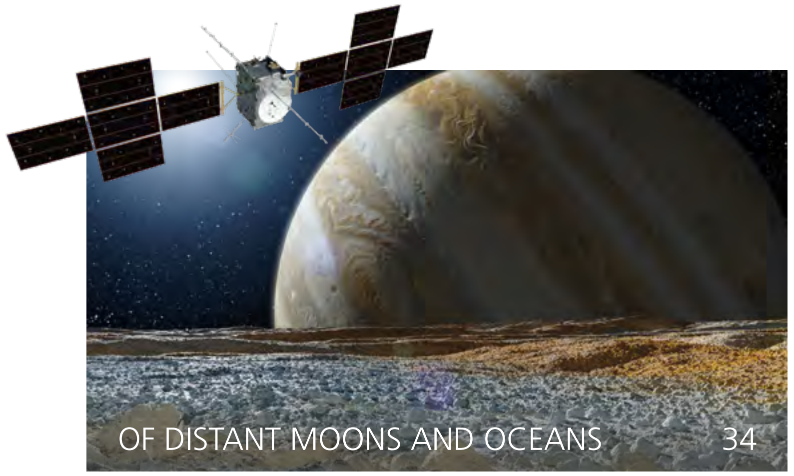
Happy holidays and a joyful New Year!

Your Editorial Team

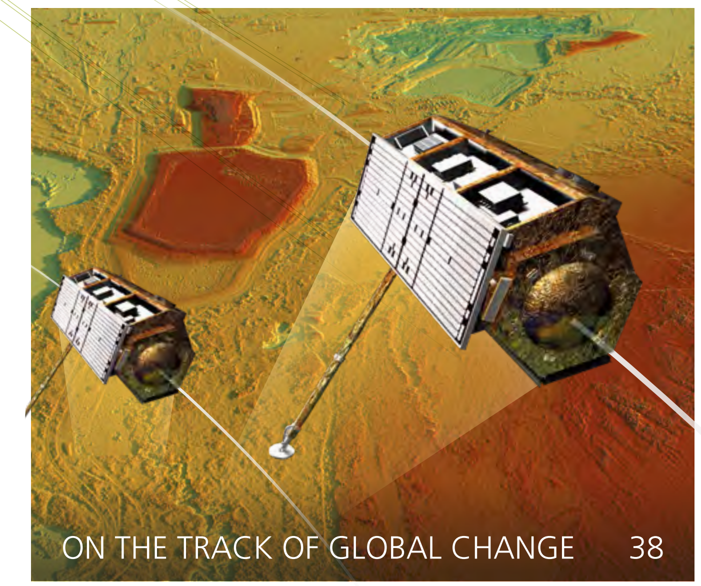
# DLRmagazine **169**

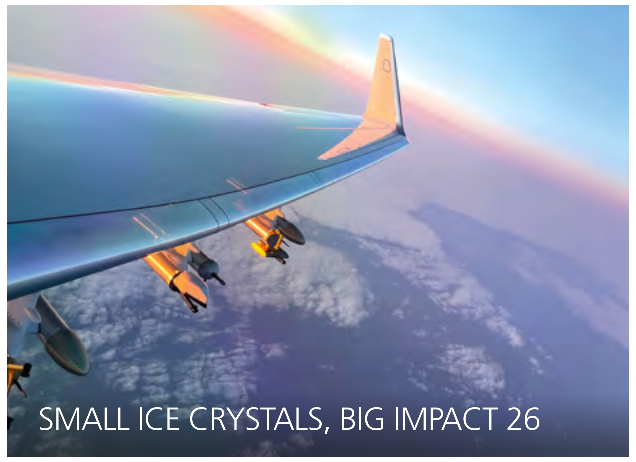

JUMPING ON BOARD THE DIGITAL TRANSFORMATION 10


AROUND THE WORLD WITH 100 EXPERIMENTS 30


OF DISTANT MOONS AND OCEANS 34


WHAT'S UP? 18


ON THE TRACK OF GLOBAL CHANGE 38


SMALL ICE CRYSTALS, BIG IMPACT 26


STRESS-FREE INSPECTION 22


COSMIC SPIRITUALITY 56


**IN BRIEF** 6

▶ **JUMPING ON BOARD THE DIGITAL TRANSFORMATION** 10
Ideas for the future of rail transport

**FIT FOR CHANGE** 16
DLR's new aviation strategy

▶ **WHAT'S UP?** 18
Discussing climate-neutral flight

**STRESS-FREE INSPECTION** 22
Improving aircraft maintenance processes

**CAUTION, BIRDS ABOUT!** 24
Warning system to prevent bird strike

**SMALL ICE CRYSTALS, BIG IMPACT** 26
HALO investigates contrails and ice clouds

**AN IMPRESSIVE FLEET** 28
DLR's research aircraft at a glance

▶ **AROUND THE WORLD WITH 100 EXPERIMENTS** 30
An ambitious research programme on the ISS

**OF DISTANT MOONS AND OCEANS** 34
DLR instruments will investigate Jupiter's satellites

**ON THE TRACK OF GLOBAL CHANGE** 38
A new digital elevation model by the TanDEM-X duo

**FULLY MIRRORED** 42
An experimental solar tower power plant

**THE PATHFINDER** 44
How algorithms learn with the help of quanta

**EVERY MINUTE COUNTS** 48
Humanitarian aid missions with I.S.A.R. Germany

**CITIES, PEOPLE, FUTURE** 50
The Smart Cities Model Projects initiative

**YOUR QUESTIONS ANSWERED** 53
DLR researchers answer questions from the community

**DEEP DIVING ON DRY LAND** 54
An extraordinary feat in the TITAN pressure chamber

**COSMIC SPIRITUALITY** 56
The Tom Sachs exhibition in the Deichtorhallen

**REVIEWS** 58

# PERSEVERANCE OBTAINS FIRST MARS ROCK SAMPLES

NASA's Perseverance rover has been situated in Jezero Crater on Mars since 18 February 2021. DLR researchers are involved in the mission and its processes, which includes the evaluation of images acquired by Mastcam-Z. These images are used to record the geological features of the region. In September, Perseverance collected chalk-sized samples from a rock nicknamed 'Rochette', after 'La Rochette', a small town in France. It stowed these samples in airtight titanium sample tubes. This is the first set of selected materials from another planet. With the help of these samples, researchers are looking to answer the question of whether microbial life could have existed on Mars in the past, when liquid water was still flowing on its surface. The samples from today's ice-cold, dusty and inhospitable planet will be transported to Earth by several NASA and ESA follow-up missions scheduled to begin in the early 2030s.

This image shows two holes where the rover's drill obtained samples of 'Rochette'. The rover obtained the first sample on the right side of the rock on 1 September 2021, and the second sample on the left on 7 September. Below the hole on the right is a round spot where the rover abraded part of the rock's surface.

NASA/JPL-Caltech


Tierney – stock.adobe.com

The 5G mobile communications standard is considered a key technology for the digitalisation of society

# TESTING 5G TOGETHER

In the 5G laboratory, DLR researchers are working with partners from other research organisations and industry to determine the real-world benefits of the 5G mobile communications standard. It is based on a software platform that connects vehicles, infrastructure elements, data platforms and services. Interested companies, municipalities and cities can access the results from the laboratory via the 5G forum, contribute their own data and test applications using the laboratory infrastructure. In the area of mobility, for instance, researchers are testing the use of a rescue drone.

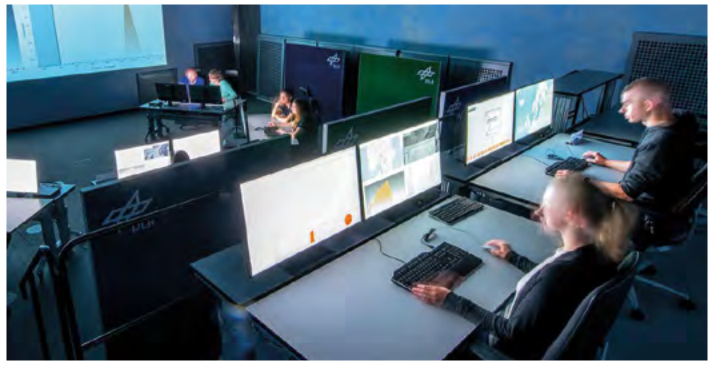
5G also offers a solution for increasingly complex construction projects. In the summer of 2021, the researchers worked with Assmann Beraten + Planen to test various 5G applications in an industrial development. Researchers from the Technical University of Braunschweig were also involved in the 5G laboratory and evaluated various communication standards between vehicles.

# DRIVING AND HEATING WITH HYDROGEN CARS

Hydrogen cars can do more than just drive; they can also function as mobile power plants. The vehicle's fuel cells can deliver high levels of electricity and heat. In addition to driving the vehicles, the cells can be used as independent units or connected to power grids. As a decentralised energy storage system, hydrogen cars can help to balance out fluctuations in the output of renewable energy sources and stabilise distribution networks. The DLR Institute of Vehicle Concepts in Stuttgart is developing methods to coordinate the flow of energy between vehicles, consumers and distribution networks. DLR researchers are now testing these methods with the help of a car that has been converted to use hydrogen. For this purpose, the vehicle's fuel cell has been fitted with external connectors. With its tank, which can hold 6.3 kilograms of hydrogen, the vehicle can generate approximately 100 kilowatt-hours of electricity. This corresponds roughly to the average monthly consumption of a one-person household. Waste heat is generated in the fuel cells. With 20 kilowatts of heat and electrical output, the vehicle can already heat a modern house.

Hydrogen cars at the DLR site in Stuttgart

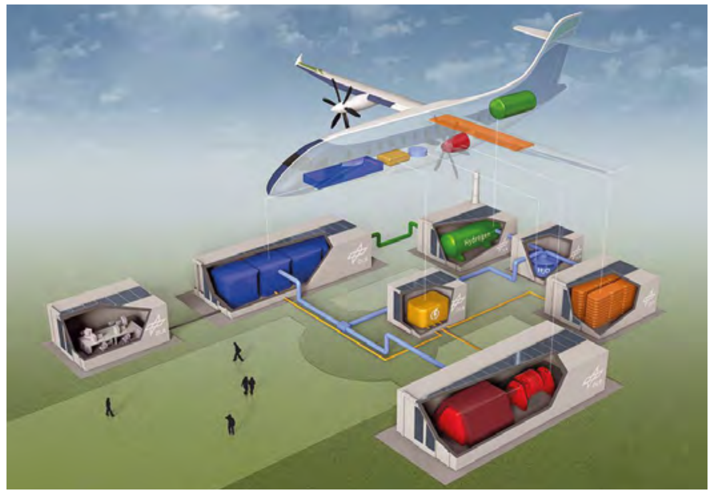
# CENTRE TO COORDINATE THE LAUNCHES OF SMALL SATELLITES



The first demonstrator for the Launch Coordination Center will be set up by the DLR Institute of Flight Guidance at its Braunschweig site. The Airport and Control Center Simulator (ACCES) is one element of the basic infrastructure.

Experts estimate that over 15,000 satellites will be launched during the current decade. A large number will be used for communications, navigation or Earth observation. Many will be delivered into orbit using microlaunchers. This will require coordination with air transport and maritime navigation activities. DLR is developing a Launch Coordination Center (LCC) in Braunschweig. A first demonstrator will show how a large number of launches and re-entries can be safely coordinated with air transport and maritime navigation activities in the future. The centre will use software-based procedures to enable the safe, efficient and flexible execution of space activities during launch and re-entry, particularly through airspace. Missions will be supervised and supported throughout the entire process, from planning to real-time monitoring and evaluation. By 2024, the first LCC demonstrator will be set up by the DLR Institute of Flight Guidance with the support of DLR Technology Marketing.

# A TEST FIELD FOR FUEL CELLS



Schematic representation of the BALIS test field, where fuel cells for air transport are to be developed.

At the innovation campus in Empfingen, in the northern Black Forest, a test field is being built on 2000 square metres where powertrains for various modes of transport, such as aircraft, can be developed and tested. The focus is on fuel cell systems with an output of around 1.5 megawatts. These would be suitable for powering regional aircraft with 40 to 60 seats and a range of 1000 kilometres. The DLR Institute of Engineering Thermodynamics is responsible for the BALIS project. The test field represents the entire system, that is both the hardware and the infrastructure with fuel cell systems, hydrogen tanks, electric motors as well as control and monitoring technologies. The first tests are scheduled to start in 2023.

**REGIONAL NEWS**

AUGSBURG: Construction work has begun at the DLR Institute of Test and Simulation for Gas Turbines on the grounds of the Augsburg Innovation Park. In future, materials, components and entire engines will be tested and optimised in the new institute building with the help of the 'virtual engine'. The planned structure comprises a four-storey office building including laboratories and a large hall with infrastructure for the test benches. It is scheduled for completion at the end of 2023.

BRAUNSCHWEIG: The DLR Institute of Transportation Systems has developed and constructed a VRU simulator. VRU stands for Vulnerable Road Users and the name says it all: cyclists and pedestrians are the most vulnerable participants in road traffic. So far, however, they have not been sufficiently taken into account in research on automated driving. Existing simulations can now be expanded upon, allowing the transport system to be examined in all its complexity.

COLOGNE: DLR's C.R.O.P.® biofilter converts nitrogen-containing wastewater into a fertiliser solution using a purely organic method of processing. In autumn, the biofilter was successfully used to process organic manure. DLR experts worked together with farmers, primarily to optimise the filter and then to test it in the fields.

NEUSTRELITZ: According to the current German Federal Transport Infrastructure Plan, by 2030, freight traffic via inland waterways within Germany is to grow by 23 percent. As part of the DigitalSOW project, researchers from the DLR Institute of Communications and Navigation are investigating the potential of highly automated and autonomous inland waterway traffic. DLR is involved in setting up the Spree-Oder-Wasserstraße, which will serve as the test environment.

OBERPFAFFENHOFEN: In the newly established Galileo Competence Center, DLR researchers are further developing the European Galileo satellite navigation system. Among other things, they analyse the performance of Galileo and other existing systems and develop, test and evaluate new ideas and promising technologies.

**DLR.DE/EN:**
**VISIT THE DLR PORTAL FOR THE LATEST NEWS**
All articles can be viewed online in the news archive with images or videos.

DLR.de/News

## TO THE TROJANS & GREEKS WITH LUCY: A MODERN VOYAGE BACK IN TIME

On 16 October 2021, NASA launched its Lucy mission towards the Trojans, a group of asteroids in Jupiter's orbit. This mission is the 13th in NASA's 'Discovery' class and is set to visit eight asteroids in 12 years. The Trojan asteroids are believed to be 'time capsules' for the Solar System, as they would have remained relatively unchanged since its creation. Using an array of spectrometers to study their chemical, mineralogical and physical attributes, Lucy aims to study these asteroids to learn more about the early Solar System. Once it reaches these asteroids in 2027, it will be the first time bodies orbiting the Sun at Lagrange points will be visited. Hopefully these Trojans will provide us with some ancient wisdom about our place in the Universe. DLR is involved in the mission's scientific activities.

NASA/JPL-Caltech

'Trojans' and 'Greeks' along the orbit of Jupiter

## NEW HEAT TRANSFER MEDIUM IN THE EVORA MOLTEN SALT PLATFORM

In a world with increasing energy demands, efficiency is key. Solar power plants are a promising alternative energy source for a sustainable future, and studies are being undertaken to find how to make them more efficient. One such strategy is changing the usual oil-based heat transfer medium in parabolic trough solar power plants to a molten salt alternative. Whereas oil-based transfer media work at a maximum of 400 degrees Celsius, molten salt can raise this maximum to 565 degrees. This substantial increase in temperature results not only in higher energy generation efficiencies, but also in lower generation costs. This method is currently being tested in the Evora Molten Salt Platform, with several parameters being carefully monitored.

Four HelioTrough® collector modules with a total length of 684 metres

## HAGGIS & LABSKAUS ENSURE GREATER SAFETY AT SEA

With the increasing amount of produce being shipped overseas comes a higher risk of accidents. Considering this, automated assistance systems for autonomous ships are being developed based on existing data about shipping movements and environmental conditions. Simply put, this could be compared to the assisted parking function available in many modern cars. These systems include HAGGIS, a virtual co-simulation that includes AI-based environment, traffic and ship simulators, and LABSKAUS, a physical testbed in which marine systems can be assessed under real-world conditions. These systems are being tested by DLR in the e-Maritime Integrated Reference Platform (eMIR) and are expected to increase maritime safety.

OFFIS Institute for Information Technology

A view into one of the two eMIR containers, in which simulators can be located.



## DLR INAUGURATES ITS INSTITUTE FOR THE PROTECTION OF TERRESTRIAL INFRASTRUCTURES

No system is completely invulnerable. Between acts of terrorism, cyberattacks and natural disasters, there are many ways that infrastructure may become damaged. This is why DLR is proud to present its Institute for the Protection of Terrestrial Infrastructures. Opened on 23 November 2021, this branch of DLR uses digital twins of structures including but not limited to water supply systems, transport networks, hospitals and storage sites for hazardous materials in order to simulate threat scenarios. These digital twins can help researchers to identify vulnerabilities in infrastructure in order to address them properly. This task will be divided between three departments: Resilience – Models and Methods, Detection Systems, and Digital Twins for Infrastructures. Together, they can create a security network to protect infrastructure components against numerous potential threats.

DLR opens an institute to research the protection of critical infrastructure

## DELIVERY OF NEW 'DO 228' RESEARCH AIRCRAFT D-CEFD

The new DLR 'Do 228' D-CEFD research aircraft

Have you heard? The recent UN Climate Change Conference (COP26) has agreed to push towards climate-neutral air transport. This presents a renewed engineering challenge for DLR researchers. To achieve this goal, hybrid-electric propulsion systems are being developed, notably to be used on feeder and regional routes. These hybrid systems will be tested with the new Do-228 research aircraft D-CEFD, and will include the use of a hydrogen fuel cell. Research will first be conducted on the individual components, then on the system as a whole, aiming to obtain an airworthy hydrogen fuel cell by the middle of this decade. The system will be an electric powertrain that uses hydrogen as its primary energy source, allowing for more sustainable air transport. The use of electric propulsion systems and fuel cells calls for systems with a high level of performance, reliability and safety. The new research aircraft now makes it possible to test a wide variety of components and entire propulsion systems in detail under real operating conditions.

## ULTRA-LIGHT AND SUPER-FAST EXTRASOLAR PLANET DISCOVERED

As far as extrasolar planets go, 'GJ 367 b' is a featherweight. With half the mass of Earth, the newly discovered planet is one of the lightest among the nearly 5000 exoplanets known today. It takes the extrasolar planet approximately eight hours to orbit its parent star. With a diameter of just over 9000 kilometres, GJ 367 b is slightly larger than Mars. The planetary system is located just under 31 light years from Earth and is thus ideal for further investigation. The discovery demonstrates that it is possible to precisely determine the properties of even the smallest, least massive exoplanets. Such studies provide a key to understanding how terrestrial planets form and evolve. An international group of 78 researchers led by Kristine W. F. Lam and Szilárd Csizmadia from the DLR Institute of Planetary Research report on the results of their studies in the scientific journal Science.

SPP 1992 (Patricia Klein)

Artist's impression of Planet GJ 367 b

DLR/DFD-WIS

# JUMPING ON BOARD THE DIGITAL TRANSFORMATION

## How DLR is preparing rail transport for the future with innovative ideas, concepts and technology

By Denise Nüssle

**The railway was one of the most significant inventions to come out of industrialisation. It transported people and goods over long distances at previously unimaginable amounts and speeds. The world of locomotives, wagons and rails has always driven technology to the next boundaries – for example achieving ground transportation speeds above 350 kilometres per hour. Now, rail transport is facing a new challenge – making an intense breakthrough into the world of digitalisation and automation. DLR's transport research experts are in no doubt about it – something, in fact, quite a lot, is happening on the railways. Let's take a look at these developments.**

Automation, new communications technologies and standards, and the use of machine learning and artificial intelligence have the potential to make rail transport much more appealing and competitive. They pave the way for significantly higher route capacity and greater efficiency overall. At the same time, they promise reduced energy consumption and increased safety, punctuality and comfort. The need for future-oriented technologies and innovative solutions for tomorrow's railways is considerable: "State-of-the-art, climate-friendly rail transport is playing a key role in the transport transition," says Karsten Lemmer, DLR Executive Board Member responsible for Innovation, Transfer and Research Infrastructure. "The volume of passenger and freight traffic is set to keep on growing all over the world. The demand for mobility that is as climate neutral as possible will grow at the same time. More intensive use of rail transport can be an important part of the solution."

*"With increasing automation, the role of humans changes. Instead of initiating tasks, people fix faults or monitor operations, conduct checks and take care of maintenance."*

**Jan Grippenkoven**

In the Next Generation Train project, DLR scientists are developing new concepts for future rail transport. The complete train family is shown together here – consisting of the NGT Link feeder, the NGT high-speed train and the NGT Cargo for freight transport.

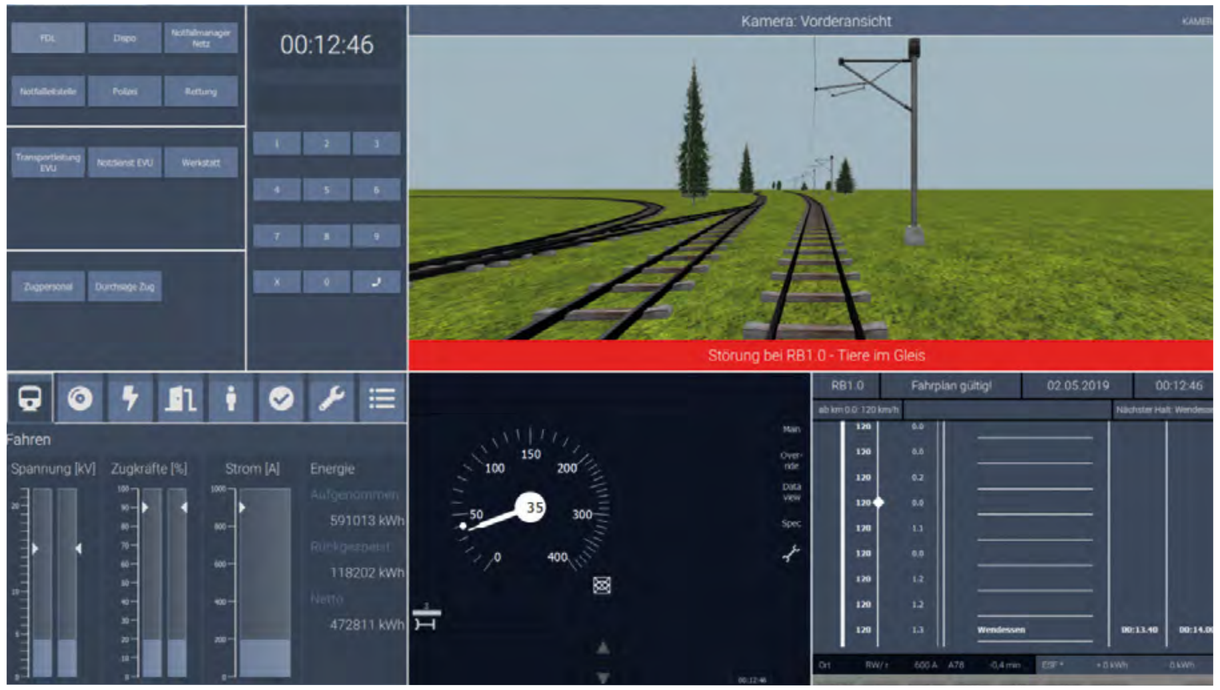
### Automated rail operations and the human factor

In road transport, automated and networked driving is an important trend and a driver of innovation. Driverless underground trains and metro services already operate in many European cities. In Australia, automated freight trains transport iron ore from the outback to ports on the coast. So, in some areas, rail transport is a true pioneer of automation. However, it is difficult to transfer this to the entire rail network. The fact that high-speed trains share large parts of their route network with much slower passenger and freight trains complicates the implementation of automated and networked railway operations. In addition to technology, people will thus continue to play an important role.

"With increasing automation, the role of humans changes. Instead of initiating tasks, people fix faults or monitor operations, conduct checks and take care of maintenance. Recognising and understanding whether the automation is faulty or why it may be acting in an unexpected way is very important," explains Jan Grippenkoven. He works at the DLR Institute of Transportation Systems, where researchers are studying the interaction between humans and automation in the rail transport sector. Among other things, the scientists are conducting studies in special simulators to research the psychological challenges associated with this area. One example is the Railway Simulation Environment for Train Drivers and Operators (RailSET). This laboratory realistically reproduces the train drivers' workplace and tasks, in the form of a virtual railway route, complete with signals and level crossings. It can simulate information and assistance systems, as well as different levels of automation. "Even when the level of automation is low, monotony and fatigue effects soon appear. People lose their situational awareness and their ability to intervene quickly is impaired. The probability of errors increases," says Grippenkoven. For this reason, it is particularly important to have work processes with alternating levels of action. Train drivers and dispatchers must not be completely detached from the processes and must be aware of the importance of their task, as they are responsible for hundreds of passengers and tonnes of freight.

In RailSET, the workplaces of train drivers and dispatchers can be realistically represented. In this way, influencing factors can be varied at will and their effects on people can be examined. The simulator is located at the DLR Institute of Transportation Systems in Braunschweig.

The DLR RailSET laboratory




If disruptions occur, a remote train operator could control the trains in the future. This operator would sit in a control centre and work with a program that visualises all important processes in real time.

Investigation of traffic behaviour at a level crossing in Braunschweig. The results showed that, on average, a road user crossed the tracks illegally every sixth red phase.

**Key technologies for automated rail transport**

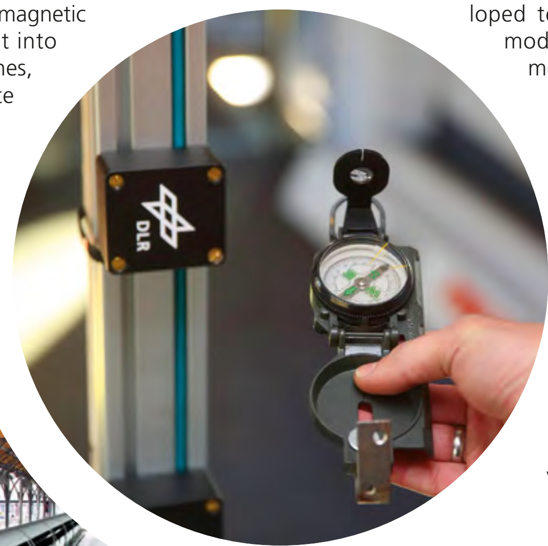
A train usually consists of multiple carriages or wagons. If these have their own propulsion system, they are referred to as railcars. Today, the individual components of a train are often still connected with mechanical couplings. These transmit tractive and compressive forces during acceleration and braking. A large number of different mechanical coupling systems are used around the world, some of which are semi-automatic, others fully automatic. In freight transport, the individual wagons are often coupled or uncoupled manually, which is very labour intensive and time consuming. This is why efforts are currently underway across Europe to convert to Digital Automatic Coupling (DAC). This system will automatically connect freight wagons and their power, data and compressed air lines.

DLR researchers are already looking a little further into the future, examining the use of new communications technologies and standards such as 5G mobile, and innovative localisation methods. With the 'virtually coupled train' concept, the individual parts of the train could travel close together. They are no longer mechanically connected, but are linked digitally. The real metal coupling is replaced by a virtual coupling based on data. In this way, wagons and trains can connect independently to form longer units and then separate again, if necessary, all while in motion. To ensure that this works safely and reliably, the distance between the units must be constantly calculated and, if necessary, corrected. This all has to happen digitally and automatically, of course. "Virtual coupling systems can make rail operations much more flexible and efficient. Shorter distances between trains or train components can also increase transport capacity," says Holger Dittus of the Vehicle Energy Concepts Department at the DLR Institute of Vehicle Concepts. "On high-speed routes, intermediate stops can be served by a single part of the train without the main train having to stop. This allows trains to make better use of maximum speeds on existing routes."

*"Virtual coupling systems can make rail operations much more flexible and efficient. Shorter distances between trains or train components can also increase transport capacity."*

**Holger Dittus**

Ensuring accurate localisation and secure and fast communication between trains or train components is both the key technological prerequisite and the greatest challenge in using virtual coupling. Both require solutions that are independent of the rail infrastructure and work at high speeds. They also have to have built-in redundancy in order to ensure safe operation even if a part of the system fails. Global satellite navigation systems and radar and lidar sensors use radio waves or laser beams to measure position, distance and speed. The DLR Institute of Communications and Navigation is also investigating and testing the use of magnetic field signatures. A lot of metal is built into railway infrastructure – tracks, powerlines, bridges, cables and reinforced concrete walls. This affects the magnetic field; it interferes with a magnetic compass. The level of interference varies from place to place. "This is what we use to determine information about position, track and speed. This method also works very well in tunnels," says Andreas Lehner from the Institute of Communications and Navigation.



Mobile radio technology can be used for communication between trains or train components. A high level of reliability, security, and low latency are also important. Latency is the physically induced delay in the transmission of data. With the latest 5G standard, this latency is less than one millisecond. In light of this, DLR has developed technology including a new type of radio module that transmits radio waves in the millimetre range – a frequency range that is set to see greater use in future mobile communications with the advent of 5G and 6G. Initial studies have shown that stable and secure communication can be established up to a distance of approximately 130 metres.

**Smart freight wagons and inter-modal cargo terminals**

Freight transport is currently dominated by 'block trains'. These transport a large, uniform amount of freight, such as cars or containers. Single wagonload freight, in which a freight train consists of wagons with cargo from different clients, is associated

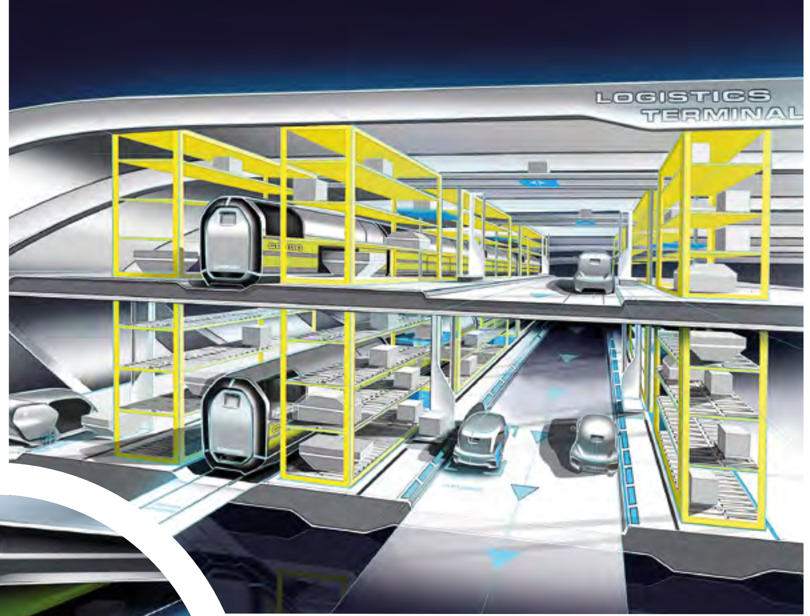
Although the idea of using Earth's magnetic field for orientation and navigation is not new, reading out the stationary part of the data from a magnetic field sensor and using it for localisation is. The IMPACT project is investigating this new navigation method. (Image above).

The NGT high-speed train links nodes quickly, efficiently, comfortably and safely. The NGT Link serves as a feeder. (Images on the left).

with complex processes and rigid operating procedures. Some 30 to 40 percent of the costs are incurred just in connecting and separating the train components. Numerous manual coupling processes are involved, resulting in long downtimes; the average speed of single wagonload freight traffic in Germany is just 18 kilometres per hour. As a result, rail is not particularly attractive for the growth sectors of courier express parcel services, food and general freight transport. A team made up of researchers from several DLR institutes is looking to change all that. They are working on a future-oriented concept for rail freight transport as part of the large Next-Generation Train (NGT) project. This comprises a railcar train, the NGT Cargo, and a new type of freight yard, the Next-Generation Station (NGS) Logistics Terminal.

The goal of NGT Cargo is to shorten transport times, be more flexible and punctual, and reduce costs. The researchers want to achieve this by giving the train concept a modular design wherever possible and providing a separate, uninterruptible power supply for all the individual wagons. "This serves as the basis for any form of automation and is essential for reliable data communication and the digitalisation of many on-board functions," says David Krüger of the DLR Institute of Vehicle Concepts.

The automated NGT cargo trains will be composed of individual wagons and high-performance power cars that can be automatically coupled as required. The train set stays together for as long as the logistics require, after which the routes of the individual wagons are separated again. "Each smart freight wagon knows its destination and receives updates from the traffic control centre if necessary. It has its own propulsion system based on electric motors and a battery that stores the energy recovered during braking. This means that the individual wagons can manoeuvre independently, eliminating the need for extra personnel and shunting locomotives or overhead lines," says Krüger, describing the concept. The individual wagons will also be able to travel the last few kilometres to their respective customers independently and will be equipped with sensors for this purpose. This will allow their location to be determined at any time and customers will receive precise information on the current status and expected arrival time of their freight.




Rack storage in the Logistics Terminal concept is positioned alongside the train wagons. Goods are automatically pre-sorted and temporarily stored directly beside the track.

The NGS Logistics Terminal will be equipped for this type of train traffic and form the interface between NGT Cargo and local freight traffic. Intermodal freight stations will link rail with road or airspace at logistically advantageous junctions. Autonomous trucks, cargo bikes or, for particularly urgent goods, drones will then cover the 'last mile' to the destination. The main components of the Logistics Terminal will be rack storage systems that are positioned alongside the railway wagons. Goods are pre-sorted here and temporarily stored directly beside the track. The pre-sorting, loading and unloading processes will happen automatically via stacker cranes, elevators and retractable floors.

**Predictive maintenance**

Germany's rail network is around 38,000 kilometres long. Besides the tracks themselves, signalling systems, points and overhead lines also have to be checked and maintained on a regular basis. This is done using measurement vehicles and conducting inspections with appropriate measurement devices. Such complex and labour-intensive procedures are necessary in order to detect damage, replace components as a precautionary measure and determine the condition of the railway infrastructure. "Machine learning and artificial intelligence enable a whole new dimension – predictive maintenance. This means that the rail system operators receive forecasts of how materials or components will perform under the given conditions. This makes it possible to prevent damage, avoid system failures and carry out maintenance in a much more targeted manner," says Jörn Groos of the DLR Institute of Transportation Systems, describing the possible future scenario.

*"Each smart freight wagon will have its own propulsion system based on electric motors and a battery that stores the energy recovered during braking. The individual wagons can manoeuvre independently, eliminating the need for extra personnel and shunting locomotives or overhead lines."*

**David Krüger**


NGT CARGO power car with single wagon automatic coupler

In order for artificial intelligence to be able to do this, it must first be supplied with large quantities of information and repeatedly trained using examples. Data from sensors and cameras mounted on the trains play an important role in this, as they make it possible to create a digital image of the infrastructure that is as precise as possible. Historical data series and the knowledge and experience of experts are also incorporated into the algorithms and models. DLR scientists are working on systematically collecting information and using data science to transform it in such a way that artificial intelligence can work with it.

DLR has already put this technology into practice in the port railway sector. Port railways transport goods within sea and inland ports. They have to be fully operational at all times so that they can be depended upon to process and handle time-critical logistics orders. Together with rail technology company Vossloh Rail Services, the software developer IS Predict and the Braunschweig port operating company, DLR has developed an embedded condition monitoring system and tested it during shunting operations. To do this, the project team equipped a locomotive at Braunschweig harbour with a multi-sensor system consisting of cameras and acceleration and rotation-rate sensors. This equipment delivered high-resolution image data and continuously measured vibrations. From the gathered data, the researchers were able to obtain information about the condition of the track infrastructure and precise location data for each case. Based on the overall dataset, an AI-based analysis method has been developed. The system managers were then able to view the results, in the form of an overview of the current condition of the rails and any damage, via an interactive map. "Such systems can already provide valuable information for the operations management of small industrial railways, which allows personnel to carry out manual inspections in a more targeted and effective manner. In future, the further development of the analysis process will make it possible to reduce the number of manual inspections that require members of staff to be present in the track area," says Groos.

### THE FOLLOWING DLR INSTITUTES AND FACILITIES CONDUCT RESEARCH IN THE FIELD OF RAIL TRANSPORT

- Institute of Aerodynamics and Flow Technology
- Institute of Aerospace Medicine
- Institute of Communications and Navigation
- Institute of Composite Structures and Adaptive Systems
- Institute of Data Science
- Institute of Materials Physics in Space
- Institute of Materials Research
- Institute for Software Technology
- Institute of Structures and Design
- Institute of System Dynamics and Control
- Institute of Systems Engineering for Future Mobility
- Institute of Transport Research
- Institute of Transportation Systems
- Institute of Vehicle Concepts

**A holistic outlook for the future**

The rail sector consists of futuristic high-speed trains to intercity, regional, local and freight traffic, so it is an exciting yet challenging point of departure for scientific research. At the same time, it holds immense market potential for new technologies and business models. "Rail transport research at DLR draws upon our extensive expertise in almost all of the technologies relevant to the railway sector and combines that knowledge with a comprehensive perspective that takes economic, environmental and societal aspects into account.

DLR researchers are also rethinking the railway station of the future – as a mobility hub, it connects and networks people and modes of transport as efficiently and sustainably as possible.

This lays the foundation for a successful transfer into the market. Our researchers are internationally sought-after for their skill at optimising existing systems and designing entirely new concepts, always in close cooperation with industry partners," says Karsten Lemmer.

**Denise Nüssle** is a Media Relations Editor at DLR.

# FIT FOR CHANGE

## A new aviation strategy points the way to zero-emission air transport

By Andreas Klöckner and Falk Dambowksy

**In future, aviation will continue to connect the world's people, cultures and economic regions. For this to remain possible, a comprehensive transformation is necessary, because by the middle of the century, the economy and society are to be climate-neutral within the framework of the European Green Deal. Only with a thorough commitment to research and development can growth in aviation be uncoupled from its environmental impact. To that end, DLR has presented an aviation strategy that sets out a research path to achieve climate-neutral flight. The basis for this is the development of significantly more efficient aircraft that require less than half as much energy as today's models. To achieve this, they must become significantly lighter and more aerodynamically efficient. New sensor systems and innovative flight controls will both also play a key role here.**

If they are to rely solely on energy from renewable sources in future, aircraft will have to adopt climate-friendly propulsion concepts and sustainable fuels, tailored to their range and size. DLR is conducting comprehensive research into the optimal combination of low-emission aviation propulsion systems, energy-efficient aircraft technologies and a low-emission air transport system. In this way, DLR is positioning itself as a virtual manufacturer to deliver an accelerated energy transition in aviation; some 25 of its institutes and facilities are conducting research in this area. Thanks to its expertise and capabilities, as well as a unique research infrastructure, DLR has a broad understanding of aviation and all the tools needed to make it fit for the 21st century. DLR is taking on the role of architect – from fundamental research right through to applications – working in close coordination and in cooperation with the aviation industry and the wider economy. The new 40-page aviation strategy sets out the challenges that must be overcome in the coming years and decades to pave the way for zero-emission air transport. Evolutionary approaches are just as necessary as the consistent use of revolutionary technologies.

## NEW PROPULSION TECHNOLOGIES AND CONCEPTS FOR ALL ROUTES

### TURBOFAN ENGINES WITH SUSTAINABLE FUELS FOR ALL JOURNEYS, INCLUDING LONG-HAUL

Highly efficient turbofan engines and fuels produced using renewable resources offer the promise of largely climate-neutral operation on short- to long-haul flights. The entire existing fleet can benefit with minimal technical modifications to engines and infrastructure. Sustainable Aviation Fuels (SAFs) lower the carbon footprint considerably and reduce the climate impact of contrails. Comprehensive test flights, safety demonstrations and extensive sustainable production capacities are necessary for the future use of SAFs.

DLR/NASA Friz

### PROPULSION SYSTEMS WITH DIRECT HYDROGEN COMBUSTION FOR UP TO MEDIUM-HAUL ROUTES

Using hydrogen can bring local aviation-related carbon dioxide emissions down to zero. Volume, weight, integration and safety all pose particular challenges for hydrogen-powered propulsion systems. In the medium term, hydrogen will be particularly suitable for aircraft flying regionally and on short-haul routes. Research into safe and reliable hydrogen combustion and the handling of the energy carrier should lead to commercial application in aircraft in the next five years.

### HYBRID-ELECTRIC PROPULSION SYSTEMS WITH FUEL CELLS FOR REGIONAL TRANSPORT

Despite their very high efficiencies, batteries and fuel cells will only be suitable for use in small and regional aircraft for the foreseeable future. High-performance electric motors, batteries and hydrogen-powered fuel cells all need to be researched for this segment. A medium-term application for commercial aircraft may then be decided upon in the next five years.

### REDUCED CLIMATE IMPACT THANKS TO OPTIMISED FLIGHT ROUTES

Roughly two-thirds of the climate impact of aviation comes from non-carbon-dioxide effects. The greatest potential for improvement lies in their reduction, through the optimisation of flight routes. Optimised long- and medium-haul flights can be particularly effective at reducing the climate impact of contrails. Appropriate policy frameworks are required to demonstrate the commercial viability and effectiveness of climate-optimised flight routes and bring them into use over the next five years.

Aviation will require a key tool – digitalisation. Using this tool consistently should cut development times in half, by enabling most testing and verification tasks to be carried out via computer simulation. This will accelerate the transfer from research to application. DLR's expertise, interdisciplinarity and comprehensive programmatic orientation, combined with its large-scale industrial facilities, put it in an excellent position to scientifically and technologically shape the transformation towards climate-compatible air transport.

More information about DLR's aviation strategy can be found at:

**DLR.de/luftfahrtstrategie**

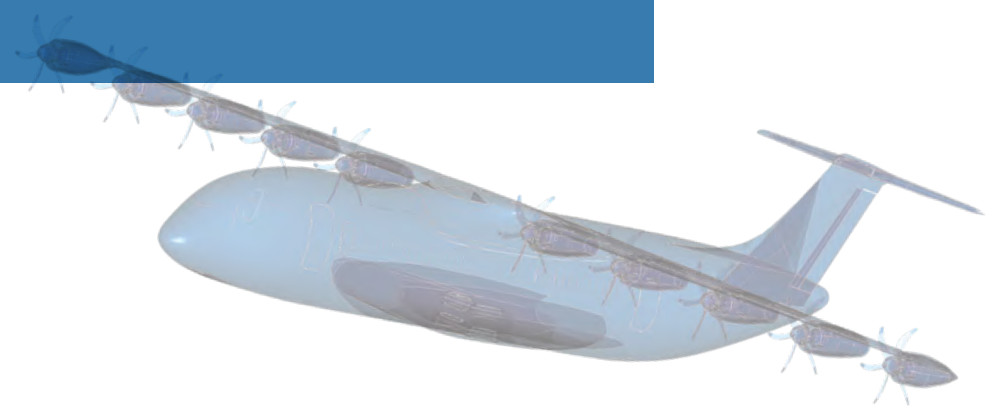
**Andreas Klöckner** is responsible for the strategy of the Aeronautics division at DLR.
**Falk Dambowsky** is an editor in the Communications and Media Relations Department.


Vision of a future hydrogen economy

# WHAT'S UP?

## Discussing climate-neutral flight

By Jana Hoidis



**What would airborne mobility have to be like to radically reduce the emissions caused by air transport? The whole world is talking about hydrogen as a possible solution. However, flying with hydrogen not only requires completely new propulsion systems, but it will also have to be produced and transported to the airport. How can these changes be made while ensuring that air transport remains economically feasible? Climate researcher Katrin Dahlmann, aircraft propulsion engineer Jannik Häßy and renewable energy researcher Veatriki Papantoni gathered to discuss how low-emission air transport might be achieved.**

**With the Climate Protection Act, the German Federal Government is aiming for greenhouse gas neutrality by 2045. What role will air transport play in this?**
**Häßy:** In 2019, before the pandemic, air traffic was responsible for approximately three percent of global carbon dioxide emissions. Business and leisure travel will likely rebound as vaccination rates increase. In addition, the global demand for air travel is expected to continue to grow in the coming decades.

**Dahlmann:** Particularly in the case of air transport, other effects, in addition to carbon dioxide, also have a considerable impact on the climate. Currently, air transport contributes five percent of the anthropogenic greenhouse effect. There is a pressing need for action to reduce air transport emissions and their impact on the climate.

**Do you necessarily have to travel less if you want to protect the climate?**
**Häßy:** In my opinion, the world is too diverse and beautiful to do without long-distance travel entirely. Intercultural exchange is important for world peace. That said, we need to ask ourselves whether every plane journey we make is necessary. Radically innovative aircraft concepts could achieve a significantly lower climate impact. The issue is that aircraft engines have long development times.

**Dahlmann:** In the shorter term, changes to flight patterns and route planning could reduce the climate impact. Flying in a lower atmospheric layer could reduce the climate-warming effect by up to 42 percent. One problem with this, however, is that the aircraft use more fuel and have to fly more slowly due to higher drag. Another possibility would be to fly around areas that are particularly prone to contrail formation. Flying long-haul in formation could also reduce greenhouse gas emissions and reduce the formation of contrails. This would require solutions in the areas of flight control and air traffic management.

**Are there any technical innovations that could help to protect the climate?**
**Häßy:** Today's aircraft gas turbines can become more efficient and emit fewer greenhouse gases through larger fans, new materials such as ceramics, or more advanced cooling technologies. In addition, Sustainable Aviation Fuels (SAFs), can be used. They lead to a closed carbon cycle, because when they are burned, they only release the carbon dioxide that was captured during their production. The use of hydrogen as a fuel makes an aircraft engine carbon-free. Hydrogen is either burned in an aircraft gas turbine or converted electrochemically in a fuel cell. However, this requires many innovations. One example is different tanks, because liquid hydrogen has a higher volume compared to kerosene and must be stored at extremely low temperatures.

**Dahlmann:** New aircraft wing designs can also help to reduce fuel consumption. This would make flying at lower altitudes significantly more cost-effective, although it would still be somewhat more expensive. Policy changes such as emissions trading could make this easier to implement in practice and create incentives for airlines.


**Jannik Häßy** has been a researcher at the DLR Institute of Propulsion Technology since 2018. He works on the conceptual design, modelling and evaluation of revolutionary propulsion concepts for air transport.

*"The first time I sit in a hydrogen-powered airliner, it will be a great feeling to know how many technical obstacles have been overcome by a multitude of people from industry and scientific research who worked to make this possible."*

**Jannik Häßy**

**Has the COVID-19 pandemic been a good time for driving innovation?**
**Dahlmann:** In April 2020 passenger air traffic dropped by 90 percent because of the pandemic, resulting in less carbon dioxide, ozone and contrails. This meant less impact on the climate in the short term. But we need long-term effects in order to protect the climate. I think the Fridays for Future campaign and the storms that occurred in Germany in summer 2021 have made the general public more aware of the problem. Even though the pandemic has had a severe impact on the entire aviation industry, now is an important time for change.

**Ms Dahlmann, carbon dioxide is often cited as the culprit of climate change, but at the beginning you mentioned other factors. What effect do these have?**
**Dahlmann:** In addition to carbon dioxide, nitrogen oxides (NOX) are also produced during the combustion of conventional fuels. These react with oxygen and generate ozone. The ozone layer in the stratosphere protects living things on Earth from excessive solar radiation. In the lower layers of the atmosphere, specifically the upper troposphere – where air transport takes place today – ozone has a global warming effect. In addition, we should not underestimate the effect of contrails. These are artificial clouds, which can retain heat within the atmosphere.

**Mr Häßy, do you already have plans for propulsion systems that could also solve these problems?**
**Häßy:** A gas turbine that is powered exclusively by hydrogen does not produce any carbon dioxide, just primarily water vapour. In addition, fewer nitrogen oxides could be produced than with the combustion of conventional or synthetic fuels. Also, no soot particles are formed, resulting in reduced contrail formation. If hydrogen is converted in fuel cells, nitrogen oxide emissions can be completely eliminated.

**Is water vapour also not a powerful greenhouse gas?**
**Dahlmann :** Yes, that is correct. However, water vapour in the upper troposphere only remains there for a very short time. At higher altitudes water vapour has a longer lifetime and thus a greater impact on the climate. Direct hydrogen combustion produces more water vapour, but studies show that this accounts for just 10 percent of the climate impact. We are currently investigating this impact with our AirClim climate model.

**Today's aircraft all operate in a similar way – with conventional gas turbines. How can new technologies be used while ensuring that airfares remain affordable?**
**Häßy:** At the moment, it is not quite clear which technology will prove itself for which application. We currently believe that fuel cells are more suitable for powering small, short-haul aircraft. For medium- to long-haul flights, the combustion of hydrogen in gas turbines could become established. The short-term alternative would be SAFs. Fuel currently accounts for approximately 20 to 30 percent of the operating costs of a commercial aircraft. SAFs will initially increase these costs. However, DLR is working on ways to reduce them again. This could be achieved, for example, through a modified fleet deployment plan. Airlines could cover shorter distances with smaller, more efficient and fully utilised aircraft. However, ticket prices will certainly increase.

**And does the carbon dioxide from the combustion of SAFs not have different effects in the atmosphere than on the ground, in the same way as ozone?**
**Dahlmann:** No, carbon dioxide is evenly distributed throughout the atmosphere due to its very long lifetime.

**If aircraft undergo these changes, then will the infrastructure, such as airports, also have to adapt?**
**Papantoni:** The more aircraft are powered by hydrogen, the greater the amount required. Lorries can carry small quantities of hydrogen to the airports. As demand increases, the expansion of a corresponding supply network becomes necessary. In regions with a high potential for renewable energies, it would be cost effective to carry out electrolysis on site.

**How much hydrogen is needed to fuel large fleets?**
**Häßy:** The energy content of hydrogen per kilogram of fuel is about three times that of kerosene. Approximately 10 million tonnes of kerosene are consumed in Germany every year, so it would only need a third of that when using hydrogen. But supply in Germany alone is not enough; the destination airports would also need to have a hydrogen infrastructure.


**Katrin Dahlmann** is a climate researcher in the Earth System Modelling Department at the DLR Institute of Atmospheric Physics. There, she maintains the climate response model AirClim, which can assess the impact of various technological and operational measures.

*"Through my work, I hope to contribute to reducing global warming, and that it will be possible to explore distant countries with a clear conscience once again."*

**Katrin Dahlmann**

This is what the short-haul aircraft of the future could look like. The direct combustion of hydrogen produces hardly any climate-impacting greenhouse gases.

**How can sufficient hydrogen be produced sustainably and economically for global air transport?**
**Papantoni:** Air transport is not the only sector requiring hydrogen; industries that would be difficult to decarbonise otherwise, such as the steel and chemical industries or shipping, also require hydrogen. Production of energy from renewable sources needs to be stepped up to meet that demand. The energy system needs to become more efficient. However, regions with little wind or sunlight will depend on imports. A higher price for carbon dioxide, for example through EU emissions trading, will make hydrogen more attractive as an alternative energy carrier.

**What is the environmental impact of producing hydrogen by electrolysis? Is this not inefficient if SAFs and hydrogen have to be produced at great expense?**
**Papantoni:** The climate impact is only one element of the overall environmental impact. Producing hydrogen requires electricity, water and the necessary plants. Up to 18 litres of very pure water are required to make one kilogram of hydrogen. So, when building a hydrogen economy, it has to be ensured that there is sufficient water available. We are also investigating the environmental impact of extracting the raw materials needed to construct the plants. SAFs and hydrogen are probably less relevant for applications that are easy to electrify, such as passenger cars. For long-haul flights or maritime applications, these energy sources provide an eco-efficient alternative. There are also synergetic effects in the production of SAFs and hydrogen. Seasonally, the amount of renewable energy that can be generated will fluctuate. It is possible to store surplus electricity in hydrogen and synthetic fuels.

**As scientists, how do you manage to foresee all of this with such clarity?**
**Häßy:** Aircraft are very complex systems. There are many interdependencies between the individual components. At DLR, there are specialists for the respective systems and disciplines. The difficulty lies in combining all of this expertise and making it usable as a whole. In the EXACT project, we are developing software that combines the capabilities of the various DLR institutes. This enables us to evaluate a whole range of scenarios involving different propulsion concepts and aircraft types, including their climate impact. Findings from the project could help industry to decide for or against a particular technology.

**Dahlmann:** Our AirClim model allows us to determine changes in global near-surface temperatures due to emissions and contrails. In combination with other DLR software tools, we are evaluating possible solutions for reducing the impact of future air transport on climate change, despite an increase in traffic.


**Veatriki Papantoni** has been working in the Energy System Analysis Department at the DLR Institute of Networked Energy Systems in Oldenburg since 2020. Her goal is to identify concepts and technologies that have both a low environmental impact and can be operated cost effectively.

*"I would definitely get on a hydrogen plane to visit my family in Greece. Travelling is even more fun if I leave a smaller ecological footprint in the process."*

**Veatriki Papantoni**

**Papantoni:** In addition to the climate impact caused by emissions, as part of the EXACT project we are examining the environmental impact of operating and producing aircraft. To do this, we are carrying out a lifecycle assessment that analyses energy and material flows over the entire life cycle. This enables us to estimate the impact on the ecosystem and human health.

**Jana Hoidis** is responsible for communications at DLR's northern establishments.

# STRESS-FREE INSPECTION

## In Hamburg, DLR researchers are investigating ways to improve aircraft maintenance processes

By Jana Hoidis


© DLR

**The new Application Center MRO (Maintenance, Repair and Overhaul) has been in operation in Hamburg since the beginning of this year. Working together with partners from scientific research institutions and industry, tomorrow's maintenance processes are being developed here.**

Part of a wing can be seen in one corner of the workshop and a test stand with a robotic arm in another. Although the workbenches at the far end appear quite conventional, what is being researched here is far from ordinary. In fact, it is highly innovative. The Head of the Maintenance and Repair Technologies Department, Rebecca Rodeck, and the Head of the Application Center MRO, Andreas Wilken, guide us through the new laboratory. Both of them work at the DLR Institute of Maintenance, Repair and Overhaul.

Few passengers worry about what happens to an aircraft before they get on board for a journey. Who actually gets it ready for take-off? What has to be checked? And yet before every departure, and at regular intervals, maintenance personnel meticulously check the technical systems and the cabin. Damaged components are always replaced or repaired immediately to ensure that the aircraft arrives safely at its destination.

### Efficient testing

Maintenance processes are essential for the safety of air transport, just as they are in other industrial sectors. Nowadays, it is more common to check more rather than less. However, processes here can be made more efficient. At present, the steps of planning, inspection and repair all have a high proportion of direct manual involvement. "This is where our research laboratory comes in," explains Rodeck. "We are able to test new digital processes on a smaller scale, which can be transferred to real test environments at a later stage." The Application Center MRO has been in operation at the ZAL TechCenter in Hamburg-Finkenwerder since January 2021. An interdisciplinary team of researchers is already working on several projects.

### Robots help people

One of the less frequent maintenance processes is the inspection of fuel tanks. These are located in the fuselage and in the aircraft wings. To carry out the inspection, the aircraft must be moved into a hangar and the kerosene drained out. Maintenance personnel then crawl into the tanks to inspect them from the inside – an arduous and even dangerous task. "We are currently working on a concept that will make it possible to conduct these inspections without draining the tanks using a submersible robot equipped with a camera," explains Rodeck.

To get an idea of the geometry of the wing, the researchers take a closer look at it in the laboratory. They think about how the robot could 'snake' through the individual chambers in the tank. The chambers become smaller and more angular towards the wingtip. Rodeck points to the wing of the aircraft. "It is very important for us to be able to support the personnel in their work. We would soon like to see a time in which no one is required to enter the tank," she says, describing her vision of more ergonomic working methods in the future. Andreas Wilken adds: "This helps to avoid mistakes and speeds up maintenance processes, which also makes flight operations more sustainable."

The Application Center MRO is modular and can be flexibly redesigned for other tests and research projects. In the future, maintenance work should be carried out in a predictive and demand-oriented manner. Even inspection data acquired manually on aircraft will be digitally synchronised with other information. Different maintenance systems can then exchange and process the data in a simple way. The experts are investigating how such processes can be technically implemented with various test setups in the laboratory. With the help of uniformly digitally processed data, the entire value chain in a maintenance company can be optimised – from the receipt of the customer's order to the delivery of material and spare parts. "We have so many visions and ideas," says Rodeck. "That is what makes research so exciting. I have always been fascinated by the possibility of helping to shape the future." Inside the Application Center MRO, the researchers hope to develop ideas about how aircraft manufacturers and operators might think about maintenance and servicing, from the very beginning right through to end-of-life recycling. The transfer of technologies to other industries is another objective.

**Jana Hoidis** is responsible for communications at the DLR site in Hamburg.

A submersible robot 'snakes' through fuel tanks in an aircraft wing. This makes inspection safer and more efficient for maintenance personnel.


© DLR

**Andreas Wilken**
from the DLR Institute of Maintenance, Repair and Overhaul heads the Application Center MRO.

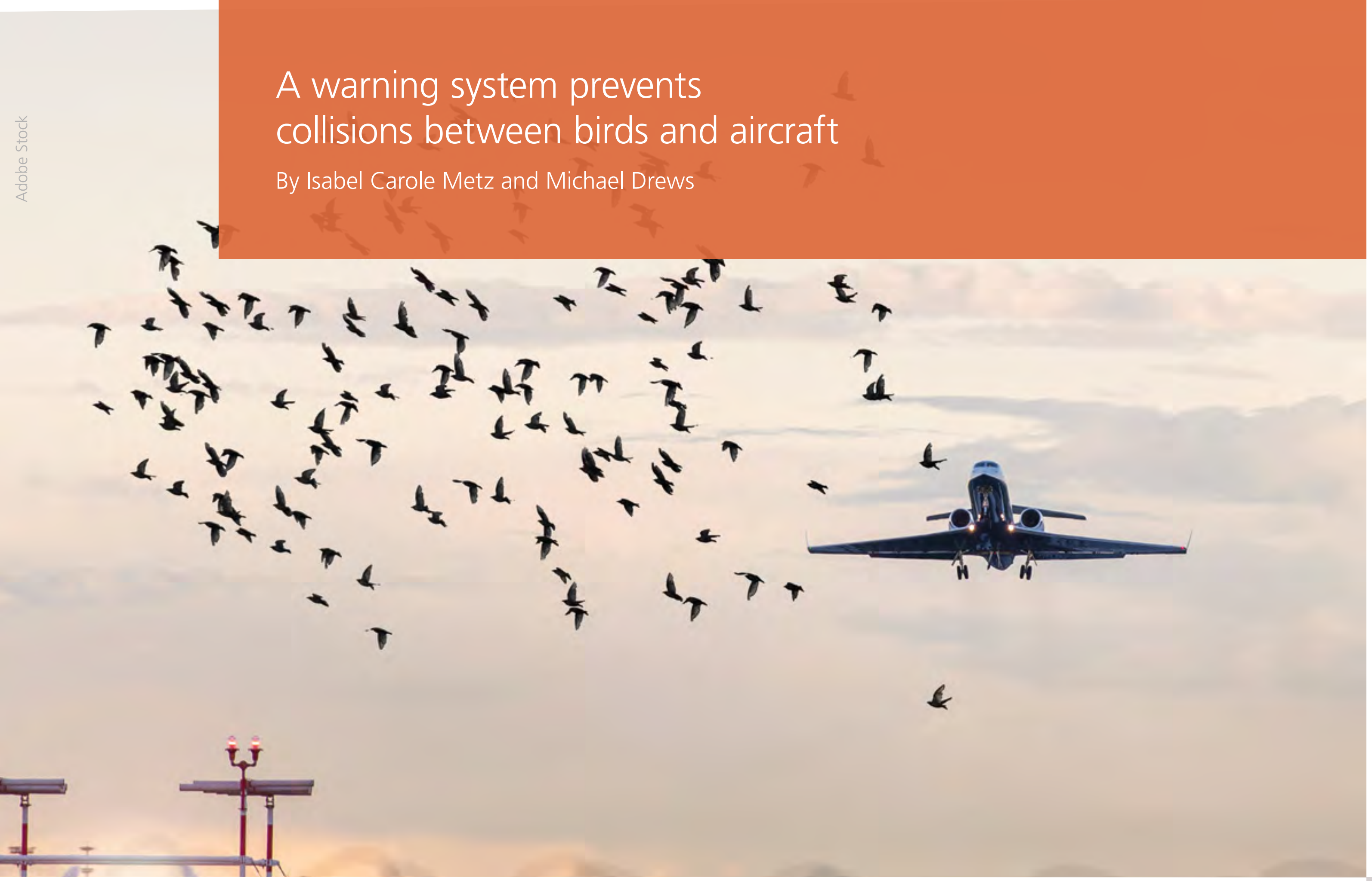

© DLR

**Rebecca Rodeck**
heads the Maintenance and Repair Technologies Department at the DLR Institute of Maintenance, Repair and Overhaul.

# CAUTION, BIRDS ABOUT!

## A warning system prevents collisions between birds and aircraft

By Isabel Carole Metz and Michael Drews



Adobe Stock

**Birds and aircraft share airspace – and this can be problematic. Collisions between aircraft and birds span the entire history of human aviation. Indeed, the first bird strike to be recorded occurred on 7 September 1905 during one of the first ever powered flights in which Wilbur Wright flew over Huffman Prairie aboard the 'Wright Flyer II'. A bird strike is also what forced the US Airways Flight 1549 to ditch in New York's Hudson River in 2009. Ten years later, an Airbus A321 had to perform an emergency landing in a corn field near Moscow after being struck by a flock of gulls during take-off. Thanks to the outstanding work of the crews and rescue teams, all passengers survived in both accidents. However, not every collision has a happy ending – since 1905, a total of 618 aircraft have been destroyed by bird strikes and 534 people have lost their lives. In 2019, approximately 1500 bird strikes were reported in Germany alone. The DLR Institute of Flight Guidance is working on a warning system to prevent these collisions.**

The risk of bird strikes is particularly high at airports as well as in the adjacent approach and departure corridors – 95 percent of these collisions occur below 1000 metres. Airports employ wildlife control units to make these areas as unattractive to wildlife as possible. This helps keep not only birds but also terrestrial animals such as muskrats and rabbits away, which significantly reduces the risk of wildlife strikes in general and bird strikes in particular near the ground. However, these measures do not affect the airspace itself – especially the approach and departure corridors or routes taken by low-flying aircraft such as drones and air taxis. Minimising the risk of collision in these areas involves those who control and navigate the flight paths – the air traffic controllers and the pilots.

**Wait until the danger has passed**

Collisions during take-off are the most dangerous, as the engine speeds are particularly high in this phase of flight, which increases the likelihood of damage. In addition, performing an emergency landing at such a low altitude with reduced or even no engine power is extremely difficult. From an operational standpoint, postponing take-offs is comparatively easy. Therefore, the warning system instructs air traffic controllers to delay take-off if it detects an increased risk of bird strikes. As soon as the danger has passed, it gives them clearance for take-off.

For the system to be able to predict the risk as precisely as possible, it needs information regarding bird movements at the particular location. More and more airports are using bird radars for the targeted tracking of birds. The concept of the warning system was tested in simulations with radar data from a Dutch airport in conjunction with weather radar information. This covered the critical airspace up to an altitude of 1000 metres. The data obtained from these experiments were organised into 'bird flight paths' using a specially developed model, and integrated into an air traffic simulator of Delft University of Technology. Using fast-time simulations, the researcher calculated how a bird strike warning system for air traffic controllers might minimise the number of collisions, how take-off delays affect runway capacity, and the extent to which delays occur in the flight plan.

The warning system is based on an algorithm that determines the severity and probability of bird strikes. To do this, it calculates the flight path of the birds and can thus predict the likelihood of a collision. It then determines the kinetic energy of the possible collision. If the risk – the probability of interference with the aircraft trajectory and the expected severity of the collision – exceeds a certain established threshold value, the system instructs the controller to delay take-off until the critical crossing bird has passed the runway or turned away.

**Thousands of kilometres of bird flight**

The efficacy of the system was proven in over 100,000 fast-time simulations. Three scenarios were compared: no system, a system that predicts collisions perfectly, and an advisory system that delays take-off based on the calculated risk. The results show that a bird strike warning system used by air traffic controllers to postpone take-off in high-risk situations causes only minor delays, even on very busy runways. This assumes that take-off is only delayed if the predicted collisions are particularly likely to occur and would result in high levels of damage.

Predicting where each individual bird will fly in the airport zone as precisely and quickly as possible is necessary to prevent bird strikes effectively in the future. To achieve this level of accuracy, the system, which is based on a mathematical model, is currently being expanded to include ecological and biological factors and trained using artificial intelligence methods. The idea of preventing bird strikes using artificial intelligence was awarded a prize in DLR's Visions competition in 2020, and is being funded in the context of this initiative.

**Isabel Carole Metz** developed the bird strike warning system while working on her doctoral thesis, in cooperation with the Delft University of Technology. She is now developing it further at the DLR Institute of Flight Guidance, where **Michael Drews** is responsible for communication.

Bird strike radar data from Eindhoven Airport in the Netherlands. The sensors record the positions and movements of both vehicles and aircraft, as well as those of birds in the vicinity of the airport.


Credit: Robin Radar Systems BV

# SMALL ICE CRYSTALS, BIG IMPACT

## Flying into contrails and ice clouds with the HALO research aircraft

By Tina Jurkat-Witschas and Christiane Voigt

**Unfurling like silvery veils across the skies, cirrus are ice clouds that form at high altitudes. Their influence on the climate is not yet fully understood. The same goes for their artificial siblings, the air traffic induced contrails and contrail cirrus – and, though it is hard to believe, the climate impact of these often-picturesque streaks of ice clouds is greater than that of the carbon dioxide emitted by aircraft. How contrails differ from natural cirrus clouds, in which regions contrail cirrus clouds have their greatest effect, and what measures can be taken to avoid them are among the most pressing questions that need to be answered in order to bring about sustainable aviation.**

Contrails form on the soot aerosol in the exhaust plumes of aircraft flying in cold regions of the atmosphere. If the atmosphere is humid enough, contrails can develop into contrail cirrus – ice clouds. After they disperse, we cannot distinguish these from natural cirrus with the naked eye, but according to the most recent findings, they make the largest contribution to the climate impact from aviation. In the CIRRUS-HL campaign, a team of scientists from nine German universities and research institutions used the HALO research aircraft to collect new measurement data in contrails as well as in natural cirrus clouds in order to find ways of reducing the impact of air traffic on the climate. The campaign was led by the DLR Institute of Atmospheric Physics.

Contrail cirrus clouds trap part of the long-wave terrestrial radiation in the atmosphere and therefore generally have a warming effect. This effect is stronger at night when there is no sunlight. During the day, cirrus clouds can even have a cooling effect by reflecting the solar radiation and thus preventing it from reaching the ground. Models also show that not every contrail cirrus cloud has the same effect on the climate and that certain regions are particularly affected by their climate impact. Investigating how cirrus



The HALO research aircraft dives into a sea of cirrus clouds over Scotland at sunset. The underwing cloud instruments measure the number and size of the ice crystals.

ice crystals change the radiation budget in mid and high latitudes was a central question for CIRRUS-HL. The team also wanted to find out how natural cirrus clouds differ from contrail cirrus clouds. Cirrus clouds have a particularly strong warming effect in northern latitudes, where there is little sunlight in the winter months and thus the reflective effect of the clouds is absent. The campaign aims to investigate the role of cirrus clouds in the strong warming of the Arctic compared to the global mean.

### From Bavaria to the far north

DLR's High Altitude and LOng range (HALO) research aircraft enables the study of natural ice clouds and contrail cirrus in a unique way. More than 25 instruments were installed on board the aircraft. These recorded the number, size and composition of ice crystals in cirrus clouds, as well as their precursor aerosol particles. In June and July 2021, the aircraft conducted a series of long flights, taking off from Oberpfaffenhofen in Bavaria towards two destinations. First, areas with high air traffic load across Central Europe to Spain and, second, the Arctic Circle – Svalbard, Iceland and Sweden. The indicators of climate change were often evident along the way – ground temperatures of 27 degrees Celsius in northern Sweden, forest fire aerosols at high altitudes, and thunderstorms with heavy rain over Germany.

### Flights through ice clouds

Thanks to HALO's impressive range, the aircraft flew through the contrails and cirrus clouds for up to eight hours, studying them from their region of formation through to dissipation. HALO flew through the clouds in staircase pattern and scanned the cirrus at different altitudes and temperatures. Over the next few years, the gathered data will help to clarify the most pressing questions about the properties and climate effects of contrail cirrus and their natural counterparts. Initial findings show that artificial cirrus clouds tend to consist of many small ice crystals, while the ice crystals of natural cirrus in the far north tend to be larger and more complex. This affects the way they interact with radiation. Long after contrails have formed, they still differ from natural cloud properties due to their numerous small ice crystals.

Since the thin, high ice clouds are difficult to predict using weather models, flight plans were often adjusted at short notice. This led to a real race to find the ice crystals.

### Can the climate impact of contrails be avoided?

How easily we take contrail cirrus for granted became evident during the first COVID-19 lockdown, when the sky was clear and a little bluer. During the CIRRUS-HL campaign, air traffic over Europe was at around 60 percent of 2019 levels. On special flights, the team has also been examining how current weather information with a contrail model can be combined for the detection of large contrail clusters with a major climate impact. The researchers also planned a slightly higher flight path that would avoid contrails as much as possible. This was used to conduct remote sensing measurements at the same time. The accurate forecasting of contrail cirrus remains a challenge for weather models. The data collected by HALO on the CIRRUS-HL mission should help to improve the models and make them more reliable. This will make it possible to plan weather-dependent flight routes that take into account the climate impact of contrail cirrus. In this way, contrails could perhaps even be avoided completely in the future, depending on the weather.

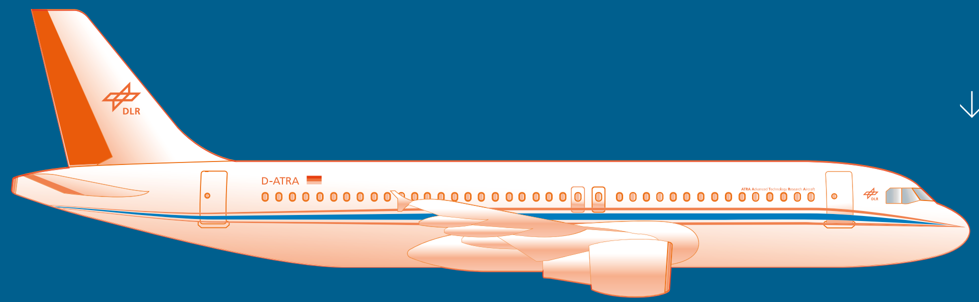
Both authors work as scientists at the DLR Institute of Atmospheric Physics. **Tina Jurkat-Witschas** is co-coordinator of the CIRRUS-HL campaign. **Christiane Voigt** is head of the Institute's Cloud Physics Department and coordinates the CIRRUS-HL project.


The HALO research aircraft was equipped with more than 25 instruments for the mission, including light-scattering spectrometers designed to detect ice particles. This measurement technique uses a laser beam, which is partially blocked by the ice particles. The shadows cast by the particles on a photodiode provide information on their size and number. These accurate instruments were installed underneath HALO's wing in order to image the ice crystals with minimal disturbance. Using the WALES high spectral resolution lidar, the scientists were able to simultaneously determine the vertical extent and optical properties of contrails and natural cirrus clouds and thus collect a comprehensive data set.

# AN IMPRESSIVE FLEET

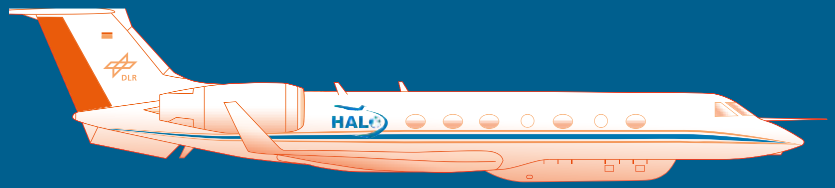
## DLR's research aircraft at a glance

DLR's wide-ranging aircraft fleet offers everything, from large commercial Airbus aircraft, to helicopters, and even gliders. With its 12 aircraft, DLR operates the largest civilian research fleet in Europe. The Flight Experiments Facility is responsible for research flight operations and operates out of two locations, Braunschweig, Lower Saxony and Oberpfaffenhofen, Bavaria. At the southern research airport in Oberpfaffenhofen, the aircraft are mostly comprised of measurement and sensor platforms for atmospheric, climate and environmental research, Earth observation, and for testing communications, radar and navigation systems. At the northern location in Braunschweig, the aircraft primarily conduct research to improve the efficiency and environmental compatibility of aircraft, with a focus on aerodynamics, aeroelasticity, flight systems and air traffic management. The oldest member of the fleet is the BO 105 helicopter with 47 years of service, closely followed by the Dassault Falcon 20 with 45 years of service. The youngest members of the fleet are the Dassault Falcon 2000 (ISTAR) and the Do 228 (D-CEFD), which will be used as a flying laboratory for electric flight propulsion systems.



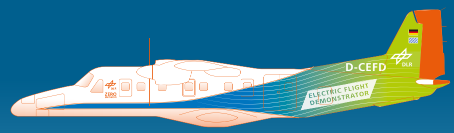
### D-ATRA
**Airbus A320**
At DLR since 2008

- Until 2020 used mainly in the fields of flight control, synthetic fuels, aerodynamics and noise reduction
- Continued use planned starting in 2023



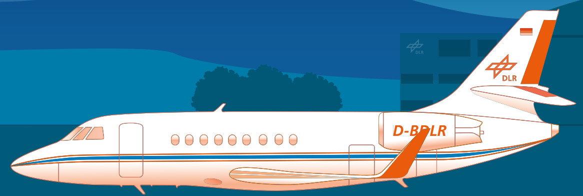
### D-ADLR
**Gulfstream G550**
At DLR since 2009

- Chemical composition of the atmosphere
- Air pollution and its transport
- Meteorology and dynamics of the atmosphere
- Formation and life cycle of aerosol particles, clouds and precipitation
- Global carbon cycle
- Transport and dynamics in higher atmospheric layers



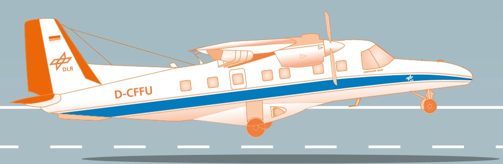
### D-CEFD
**Dornier Do 228-202**
At DLR since 2021

- Testing of technologies, components and systems for electric flight propulsion
- Fuel-cell-based electric propulsion



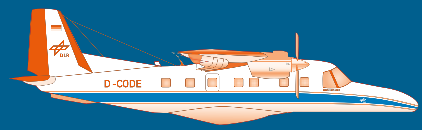
### D-BDLR
**Dassault Falcon 2000LX**
At DLR since 2020

- Digitalisation
- Automation
- Unmanned Systems
- Aerodynamics
- Flight systems and control
- Flight procedures



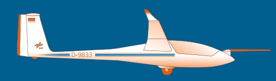
### D-CFFU
**Dornier Do 228-212**
At DLR since 1991

- Radar systems
- Hyperspectral sensors
- High-resolution aerial imaging



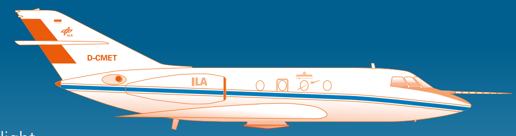
### D-CODE
**Dornier Do 228-101**
At DLR since 1986

- Technologies for remote-controlled flight systems
- Autonomous flight
- Sense and avoid
- Noise reduction



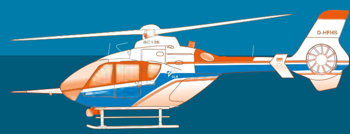
### D-9833
**Discus-2c**
At DLR since 2011

- Reference aircraft for flight performance measurements
- Testing of new measurement techniques
- In-flight mechanical and aeroelastic research
- Atmospheric measurements
- Dynamic testing of transient flight conditions with modern pressure measurement technologies
- Flight tests without vibration and electromagnetic disturbances
- Digital maintenance methods



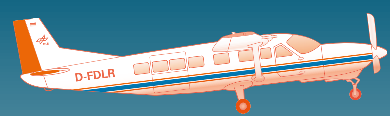
### D-CMET
**Dassault Falcon 20E-5**
At DLR since 1976

- Environmental and climate research
- Measurement of emissions from aircraft in flight
- Validation of satellite data and climate models
- Communications, navigation and surveillance



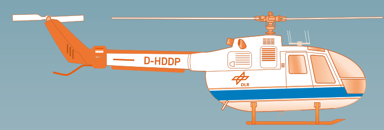
### D-HFHS
**EC 135**
At DLR since 2002

- Implementation and testing of active control elements (sidesticks), sensors and visual systems
- Testing of pilot assistance systems
- Flight characteristics measurements
- Training of test pilots and flight test engineers
- Simulation of the flight behaviour of other helicopters
- Sensor platform for high-resolution optical camera systems



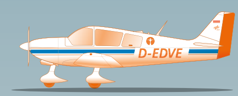
### D-FDLR
**Cessna 208B Grand Caravan**
At DLR since 1998

- Flying lecture theatre / summer school for students of meteorology or aeronautics and crewed spaceflight
- Air-quality measurements in the boundary layer and troposphere
- High-resolution aerial imaging



### D-HDDP
**BO 105 CB**
At DLR since 1974

- Traffic monitoring and disaster management
- Low-noise approaches
- Pilot assistance systems
- External loads
- Rotor flight characteristics and conditions



### D-EDVE
**Robin DR400-200R**
At DLR since 1991

- Towplane for DLR research glider Discus-2c
- Pilot training
- Intruder for 'Sense and Avoid' systems

The size of the aircraft is not to scale

Crew-3 on board the Dragon capsule. From left: ESA astronaut Matthias Maurer and NASA astronauts Thomas Marshburn, Raja Chari and Kayla Barron.

# AROUND THE WORLD WITH 100 EXPERIMENTS

## An ambitious research programme for Matthias Maurer on board the International Space Station ISS

By Elke Heinemann and Michael Müller

**"Hatch open" – on 12 November 2021 at 02:10 CET Matthias Maurer floated through the airlock of the connecting Node 2 module Harmony into the ISS, his home for the next six months. Maurer and his three fellow crewmembers journeyed from Cape Canaveral to the ISS on board a SpaceX Dragon spacecraft – a first for a German astronaut. Now the research work can begin!**

The Saarland native with a doctorate in materials science will be supervising more than 100 international experiments, 36 of which are from Germany, on board the ISS until April 2022. The experiments range from fundamental research to applied science in the areas of life sciences, medicine, materials science, physics and Earth observation. Five of these experiments are presented in this article.

Matthias Maurer will also take on several educational tasks during his mission, with the goal of inspiring the next generation to take an interest in science and technology. DLR has prepared an entire series of activities ranging from hands-on experiments and competitions to direct radio contact between the ISS and German schools. With these Amateur Radio on the International Space Station (ARISS) calls, the German Space Agency at DLR and the German Amateur Radio Club (DARC) will bring spaceflight directly into the classroom. During radio contact, pupils will have the opportunity to ask Matthias Maurer numerous questions. Twelve German schools will take part. "The tension is palpable at every ARISS event. The pupils have been preparing for weeks – and when 'This is NA1ISS, ready for your questions' is heard, space fever takes over entirely. It is great to experience all the enthusiasm and motivation a project like this can bring out in children and young people," says Oliver Amend, Chairman of ARISS Europe.

**Elke Heinemann** and **Michael Müller** work in the Communications and Media Relations Department at DLR.

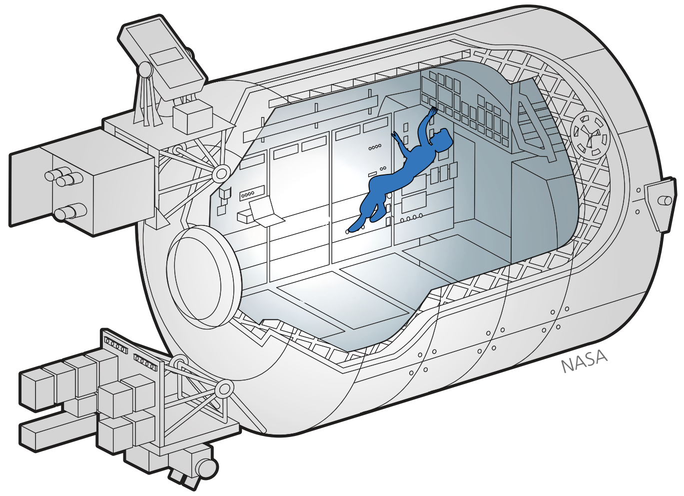
## OVERVIEW OF THE MISSION'S EXPERIMENTS

### LIFE SCIENCES

| | |
|---|---|
| **Thermo-Mini** | Body temperature regulation |
| **AI Retinal Diagnostics** | Non-invasive diagnostics |
| **EasyMotion** | Muscle simulation with a special suit |
| **Exercise Kinetics** | Kinetics of human motion |
| **Immuno-2** | Stress factors for the immune system |
| **Myotones** | Properties of skeletal muscles |
| **Immunity assay** | Human physiology |
| **CerISS** | Herniated discs during spaceflight |
| **SMASH** | Space headache |

### EDUCATION AND OUTREACH

| | |
|---|---|
| **CalliopEO** | Programming competition |
| **Granular Damping** | Granular media |
| **Touching Surfaces** | Biocontamination of surfaces |
| **Dzhanibekov Experiment** | Rotation of an object |
| **Protectors of Earth (Earth Guardian 3)** | School competition – remote sensing from space to protect the climate |
| **Hand in Hand around the World** | Painting competition |
| **ARISS calls** | Radio contact with Matthias Maurer |
| **Space Seeds II** | Wildflower cultivation on the ISS |
| **High Flyer (outside the Cosmic Kiss timeframe)** | Student competition |



NASA

### PHYSICS AND MATERIALS SCIENCE

| | |
|---|---|
| **EML** | Melting furnace for metal alloys |
| **MSL** | Melting metal in microgravity |
| **TRANSPARENT ALLOYS** | Transparent organic substances |
| **PK-4** | Complex plasmas |
| **Concrete Hardening** | Crystallisation of various concrete mixes |
| **FLARE** | Fire safety during space missions |
| **Cold Atoms Lab** | Cold atoms |
| **GraSCha (outside the Cosmic Kiss timeframe)** | Sound propagation in granular media |

### BIOLOGY

| | |
|---|---|
| **Cellbox-3** | Cell cultures in microgravity |
| **Space Fabric** | Biocidal textiles |
| **Dosis 3D Mini** | Radiation distribution on the ISS |
| **Biofilms** | Bacteria on surfaces |

### TECHNOLOGY

| | |
|---|---|
| **Cimon 2.1** | AI assistance systems |
| **On Board Training in Virtual Reality** | Astronaut training in virtual reality |
| **WICOnet – Wireless Communication Network** | Technology demonstration, communications, wearables |
| **Metabolic Space** | Non-invasive diagnostics, respiratory gas analysis, wearables |
| **ICARUS** | Animal migration, technology |
| **Laplace (outside the Cosmic Kiss timeframe)** | Planet formation |

## BUILDING MATERIALS FOR EARTH, THE MOON AND MARS

Worldwide, 38 gigatonnes of carbon dioxide are emitted annually, three of which are generated during the production of cement. In order to produce concrete (a mixture of cement, sand and water) in a more climate-neutral way, improvements are necessary at several different stages in the process chain. In particular, it is very important to gain a better understanding of the hardening process. Even the first few seconds after mixing are highly sensitive to the effects of gravity. However, the entire hardening process can take from weeks up to months.

The **MASON/Concrete Hardening** experiment promises a better understanding of concrete. On the one hand, the experiments should help enable more effective use of building materials on Earth, while on the other hand, the experiment is also important for future crewed exploration of other celestial bodies. Concrete serves as a reference for construction alternatives, such as the 3D printing of habitats from the lunar regolith dust. Measurements on the ground can clarify individual aspects of the hardening process. Valuable comparative measurements will then take place in microgravity. With the MASON experiment, scientists from the DLR Institute of Materials Physics in Space are working together with the Universities of Duisburg-Essen and Cologne, as well as with the Swiss Biotechnology Space Support Center. There is also cooperation with researchers from Penn State University and NASA.

*"For some time now, Matthias Maurer and I have been thinking about the possibilities for the optimisation of concrete, especially in light of the planned lunar analogue facility, Luna Europe. I'm very pleased that he will soon be carrying out these experiments on the ISS."*

**Matthias Sperl,** Project Manager for MASON at the DLR Institute of Materials Physics in Space.

MASON will examine various cement samples on Earth and on the ISS

## RETINAL DIAGNOSTICS USING A TABLET

Along with radiation exposure, changes to the optic nerves and the brain are among the greatest risks to astronauts. In microgravity, body fluids tend to migrate towards the head, which can lead to prolonged circulatory disorders and increased pressure inside the skull. To ensure that astronauts receive targeted treatments during their missions, the microcirculation of the blood in the brain and any increased intracranial pressure must be diagnosed non-invasively. With **Retinal Diagnostics**, this happens indirectly with the help of a clip-on lens that is attached to the camera of the crew-member's tablet with an adapter. It records changes to the retina. The condition of the retina enables researchers to draw conclusions about potential problems in the brain. The process is inexpensive and straightforward – the images and videos of the retina are transmitted from the ISS to the ground using the tablet. Analyses can be carried out using machine learning, to support ophthalmologists and neurological specialists in the early detection of possible brain damage.

In the future, this technology may be able to offer autonomous diagnosis. For future crewed exploration missions beyond Earth orbit, Retinal Diagnostics will help to ensure that crews arrive at the Moon or Mars without visual impairment or mental deterioration. Experts from the DLR Institute of Aerospace Medicine, DLR Technology Marketing and the European Astronaut Centre (EAC) are involved in the experiment.

The DLR Retinal Diagnostics team consists of Claudia Stern, Scott Ritter and Jürgen Drescher. Here, Stern and Ritter are testing the technology.

*"This technology can be used in space medicine as well as on Earth and for emergency diagnostics. A non-invasive form of retinal diagnosis could be made available to patients from underdeveloped regions as a window into the brain – by using a smartphone, for example."*

**Claudia Stern,** Head of the Department of Clinical Aerospace Medicine at DLR.

## MORE THAN JUST A FINGERPRINT

Long-term stays on board a space station can lead to the development of its own microflora, which grows from microorganisms such as bacteria, viruses and moulds carried into space by the astronauts. This can have an impact on the health of the crew. In addition, structures formed by microorganisms (biofilms) can damage equipment. Therefore, antimicrobial contact surfaces and the effective prevention of microbial spreading are important topics for space missions, as well as for public facilities, transport, hospitals and the food industry.

**Touching Surfaces** investigates new types of laser-structured antimicrobial surfaces made of copper and brass. These are being tested on board the ISS. Their effectiveness is to be confirmed in the prevailing environmental conditions of microgravity and isolation. Sample holders containing two types of antimicrobial metallic surface have been mounted at various locations on the ISS – both smooth and structured surfaces, which increase or reduce the adherence of microorganisms. The test surfaces will be touched regularly throughout the mission and then examined microbiologically and by materials specialists back on Earth. The experiment is being carried out by the DLR Institute of Aerospace Medicine in cooperation with Saarland University, University College London and the Bonn-Rhein-Sieg University of Applied Sciences.

Experiment sample carrier

*"As a project manager, I'm especially proud of the level of teamwork between the national and international partners. I was particularly impressed by the commitment of our young project scientists – setting up a space experiment in the middle of a pandemic was a great achievement."*

**Ralf Möller,** Project Manager for Touching Surfaces, DLR Institute of Aerospace Medicine.



## ELECTRICITY MAKES MUSCLES GROW

Long-term stays in microgravity can lead to a breakdown in muscle tissue in the trunk and limbs. This happens because the muscles no longer have to work against gravity. To prevent muscle atrophy and the resulting bone loss, astronauts on board the ISS have to exercise for approximately two and a half hours each day. Matthias Maurer will test the **EasyMotionSkin** system during his mission. This device consists of a special suit which has been adapted to incorporate electrodes. These electrodes emit weak electrical impulses which stimulate the muscles during training. This technique is referred to as Electrical Muscle Stimulation (EMS). The combination of increased underlying tension and targeted muscle training can significantly increase the effectiveness of exercise. The technology is not only interesting for use in space, but also in the field of rehabilitation, particularly following intensive medical treatment.

The German Space Agency at DLR, OHB System AG, EMS GmbH, the Berlin Charité hospital and the European Astronaut Centre are involved in EasyMotion. The Federal Ministry for Economic Affairs and Energy is funding the project.

*"With EMS technology, Matthias Maurer is laying the foundation for a new type of training concept for astronauts in space. If we can make daily training more effective, crews will have additional time for other, more exciting experiments on board the ISS."*

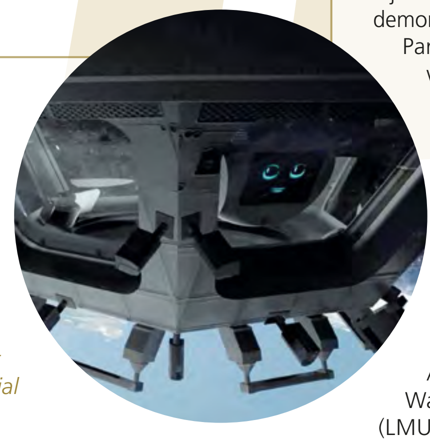
**Christian Rogon,** Department of Research and Exploration, German Space Agency at DLR.

Matthias Maurer trained with the EasyMotionSkin system on Earth in preparation for his mission

## AN INTELLIGENT COMPANION

The spherical robot **CIMON** (Crew Interactive Mobile Companion) can see, hear, understand, speak and 'fly'. This autonomous robotic assistant has been designed to support the work of astronauts and increase their efficiency. It can display and explain a wide range of information as well as give instructions for scientific experiments and repairs. The astronauts can access documents and media using voice control. This way, both their hands are free to work – a great advantage. CIMON can also be used as a mobile camera for operational and scientific purposes. It can perform routine tasks such as the documenting of experiments, searching for objects and taking inventory. After the successful technology demonstration with ESA astronauts Alexander Gerst and Luca Parmitano, the focus during Matthias Maurer's mission will on be the operational and scientific use of CIMON. It will communicate with Maurer, and guide and support him while he is conducting complex scientific work. CIMON not only helps on board the ISS – on Earth, its mission is to advance innovations for applications in robotic industrial production and education, as well as medicine and care.

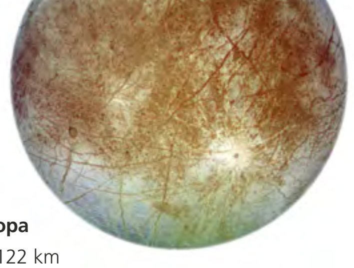
The development and construction of CIMON were commissioned by the German Space Agency at DLR with funding from the Federal Ministry for Economic Affairs and Energy, and implemented by Airbus. IBM Watson, the Ludwig Maximilian University of Munich (LMU) and the Biotechnology Space Support Center (BIOTESC) at the Lucerne University of Applied Sciences and Arts were also involved in the project.



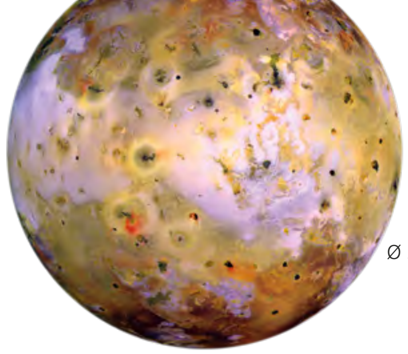
CIMON is the only talking artificial intelligence system on board the ISS

*"Matthias Maurer and CIMON form a new kind of team. Matthias is an ESA Ambassador for the German Children's Heart Foundation (Stiftung KinderHerz) – with CIMON, DLR is providing the first robotic Children's Heart Ambassador, who will be revealing a very special surprise during the mission."*

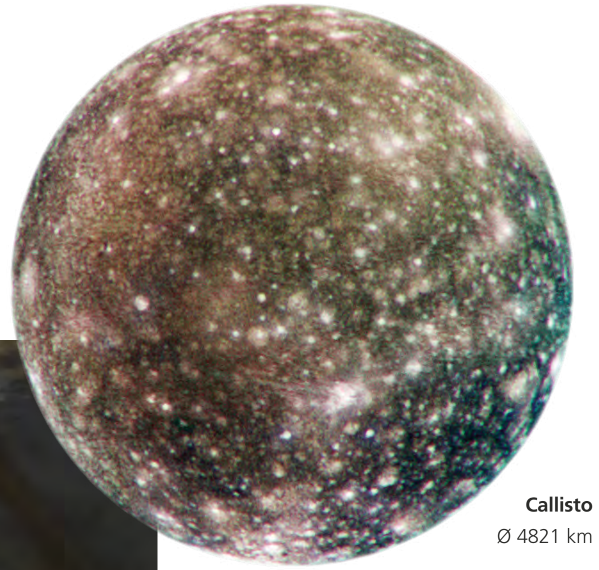
**Christian Rogon** is coordinating the project for the German Space Agency at DLR.



**Europa**
Ø 3122 km



**Io**
Ø 3631-3660 km



**Callisto**
Ø 4821 km

ESA/ATG medialab; NASA/JPL/DLR/ESA

# OF DISTANT MOONS AND OCEANS

## Two DLR instruments will investigate Jupiter's icy satellites

By Ulrich Köhler

**2022 will see the launch of the Jupiter Icy Moon Explorer, the first mission of the European Space Agency (ESA) to study the outer Solar System. JUICE is a mission of ESA's Cosmic Vision programme. On board are 10 scientific instruments, including JANUS and GALA, in which DLR is heavily involved. When it arrives in the Jovian system in 2031, JUICE will explore three fascinating worlds of ice, rock and water – the moons Europa, Ganymede and Callisto.**

In 1610, the great Tuscan polymath Galileo Galilei first observed and documented moons in orbit around Jupiter – and the first objects to orbit a planet other than Earth. In doing so, he confirmed the Copernican, heliocentric world view, which states that Earth is a planet like the others, and that they all revolve around the Sun. The Jovian moons were named after favourites of Zeus – Io, Europa, Ganymede and Callisto – and have since become known as the 'Galilean' satellites in honour of their discoverer.

**Remarkable companions of a colossal planet**

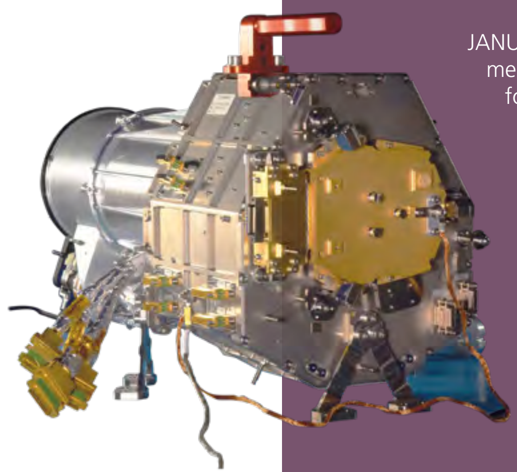
Examined by spacecraft at close range for the first time in 1973/74 during the Pioneer 10 and 11 missions, the four moons were studied in much greater detail in 1979 during the flyby of Voyager 1 and 2. The images we received revealed fascinating and very different worlds. Io, the innermost of the four Galilean satellites, is one of the most volcanically active bodies in the Solar System. High-sulphur lava at temperatures of up to 1350 degrees Celsius is spewed, giving the moon its surreal, yellow appearance. On the other hand, Europa, which is roughly the same size as the Earth's Moon, resembles a smooth sphere of ice riddled with hundreds of fractures and a temperature of minus 170 degrees Celsius. Then there's Ganymede. With a diameter of almost 5300 kilometres, it is the largest natural satellite in the Solar System. Beneath its icy shell are a rocky mantle and an iron core – which creates a distinct magnetic field, the only one found so far on a natural satellite. Last but not least is Callisto. The somewhat smaller moon is littered with thousands of impact craters. Under its icy crust, a mixture of stone and iron seems to indicate a barely differentiated body, geologically inactive very early on.

**Are there oceans on Europa and Ganymede?**

NASA's Galileo orbiter explored these four worlds between 1995 and 2003. In addition to the four large moons, 75 other satellites, some only a few kilometres in size, orbit the 140,000-kilometre-diameter gas giant. The spacecraft sent back reliable evidence to support the hypothesis that oceans must exist under the kilometre-thick ice crusts

**Ganymede**
Ø 5268 km

Moon images: NASA/JPL/DLR



LDO

### JANUS

JANUS is the camera system selected by ESA to fulfil the optical imaging scientific requirements of the JUICE mission. Short for Jovis, Amorum ac Natorum Undique Scrutator (Latin for 'comprehensive observation of Jupiter, his love affairs and descendants'), JANUS was developed in Italy, Germany, Spain and the United Kingdom. Parts of the hardware were built at the DLR Institute of Planetary Research, which also provides one of the scientific leads, Thomas Roatsch. The main electronics were developed at the Institute for Data Technology and Communications Networks at the TU Braunschweig.

One of the primary tasks of JANUS is mapping, that is, optically recording the landscapes of Ganymede and Europa and the effects of tidal forces that might be visible on their surfaces, which are responsible for the formation of the subcrustal ocean layer. In addition to a high spatial resolution, the camera system has a broad spectral range and high radiometric (light) sensitivity across 13 spectral filters. Light signals are recorded at wavelengths from 340 nanometres (blue) to 1100 nanometres (near infrared). Io and many of the small moons will also be observed from a distance.

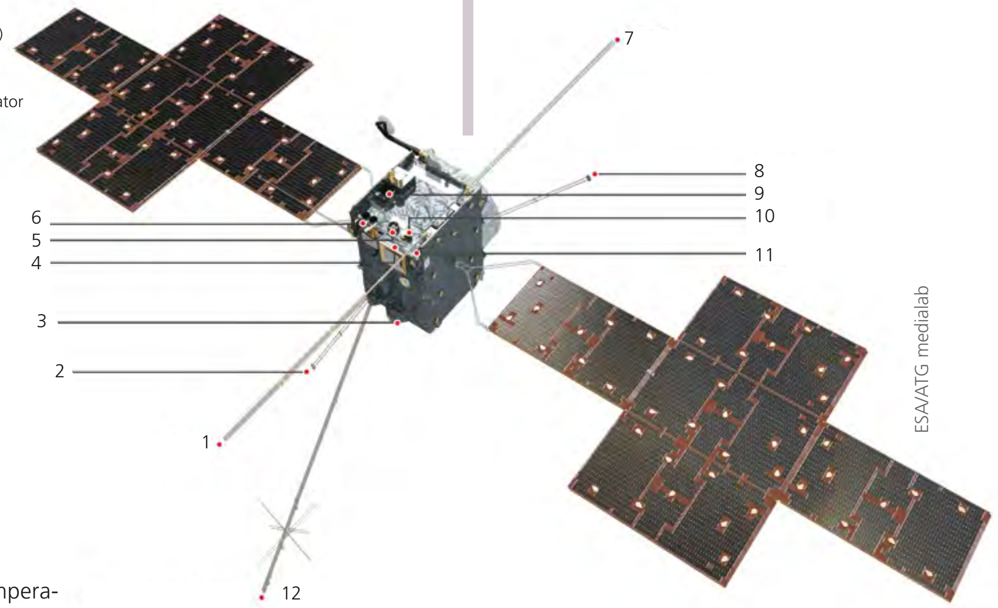
The high sensitivity is guaranteed by the powerful optics and the sensitive detector and electronics unit. JANUS has an extremely sensitive light detector that can withstand the high levels of radiation encountered in the Jovian system. The readout electronics developed for this purpose at DLR are extremely low-noise.

EXPERIMENTS ON BOARD JUICE

| | | |
|---|---|---|
| 1/7 | RIME | Radar for Icy Moons Exploration |
| 2/8 | RPWI | Radio & Plasma Wave Investigation |
| 3/9 | PEP | Particle Environment Package |
| 4 | MAJIS | Moons and Jupiter Imaging Spectrometer (visible-near infrared hyper-spectral imager) |
| 5 | GALA | Ganymede Laser Altimeter |
| 6 | SWI | Sub-millimetre Wave Instrument |
| 10 | JANUS | Jovis, Amorum ac Natorum Undique Scrutator (camera system) |
| 11 | UVS | UV Spectrograph |
| 12 | | Magnetometer beam with RPWI and J-MAG Magnetometer for magnetic field measurement |

IN THE SPACECRAFT

3GM: Gravity & Geophysics of Jupiter and Galilean Moons (radio-science)

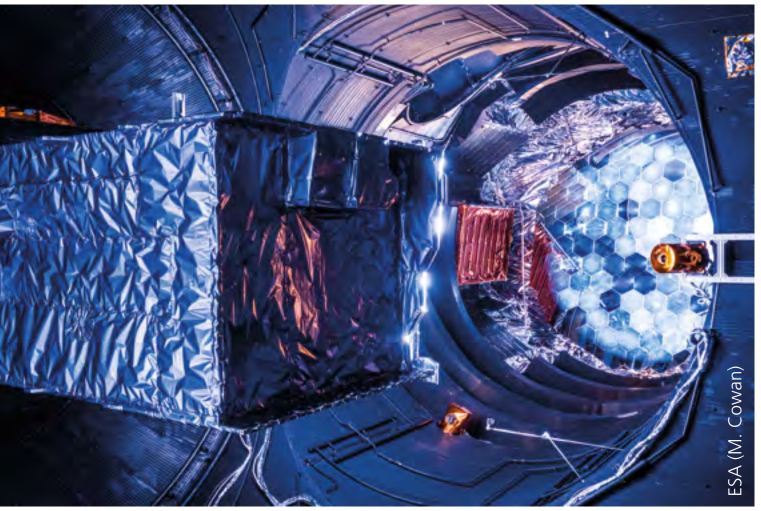


ESA/ATG medialab

of Europa and Ganymede. These could contain more water than all of Earth's oceans, and possibly even harbour life! Europa's sub-crustal ocean sometimes appears to be ejecting water onto the surface along fractures – the numerous lines in the ice are reminiscent of blade marks left by skaters – where it quickly freezes, yielding an ever-rejuvenating and changing landscape.

How is this possible, so far from the Sun, at temperatures well below minus 100 degrees Celsius? With its enormous mass, Jupiter exerts extremely strong tidal forces on its four largest moons, which deform the satellites, 'kneading' them from the inside and creating heat through friction. This heat keeps the salty water above freezing point. Io, Europa, and Ganymede are locked in a 4:2:1 orbital resonance. This means that the moons are repeatedly lined up like a string of pearls, which intensifies the tidal effect and generates even more heat. Scientists are fairly certain that warm ocean water circulates under Europa's icy crust and through the rock shell, releasing minerals that are washed onto the surface along with the water. The Galileo space probe spectroscopically detected mineral salt deposits on the ice.

Water, heat, salts – these are some of the most important prerequisites for the emergence and existence of life. Europa and Ganymede have long been considered potential habitats for microbial life beyond Earth – in an environment completely different from that of Mars, where intensive searches for traces of former (and perhaps even present) life are currently under way. This makes the Jovian system a natural target for further exploration.


ESA (M. Cowan)

A view of the JUICE Thermal Development Model (TDM) inside the Large Space Simulator at ESA's European Space Research & Technology Centre (ESTEC)

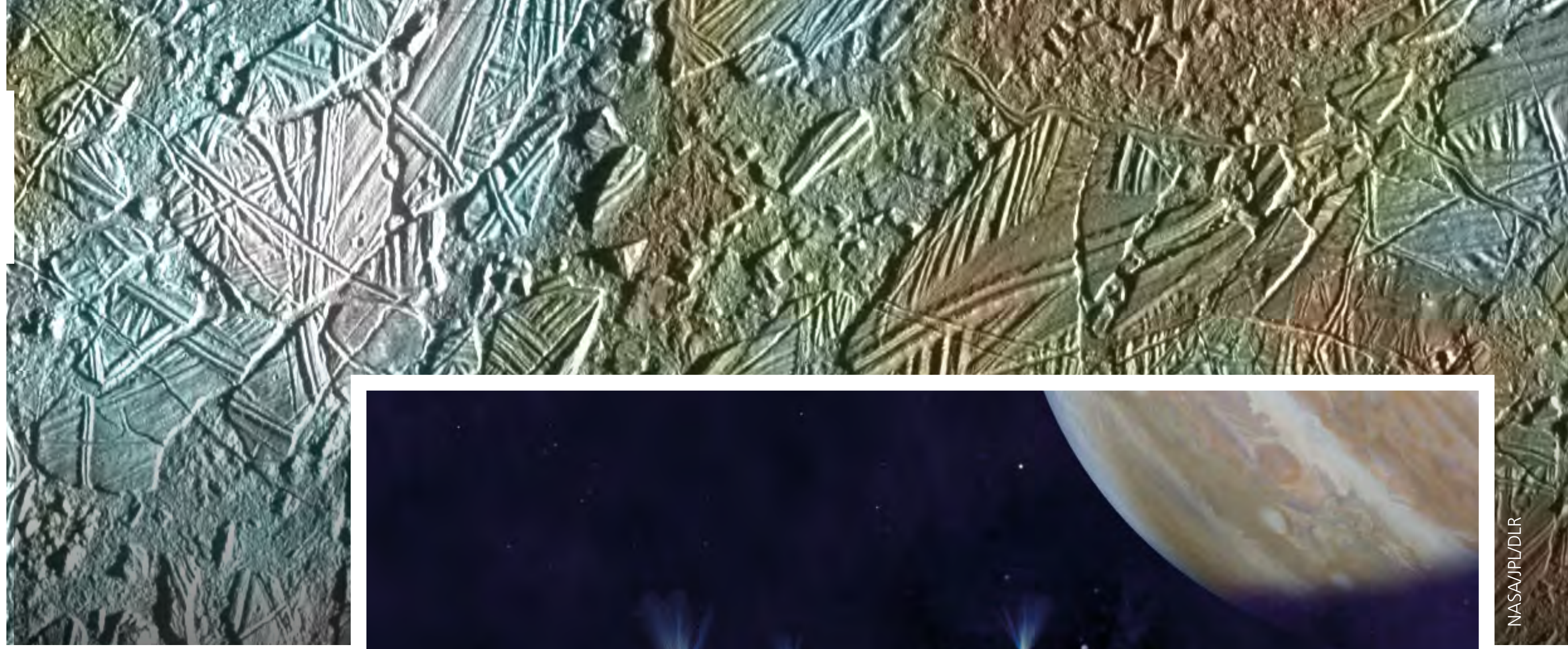
**Hidden seas and unique magnetic fields**

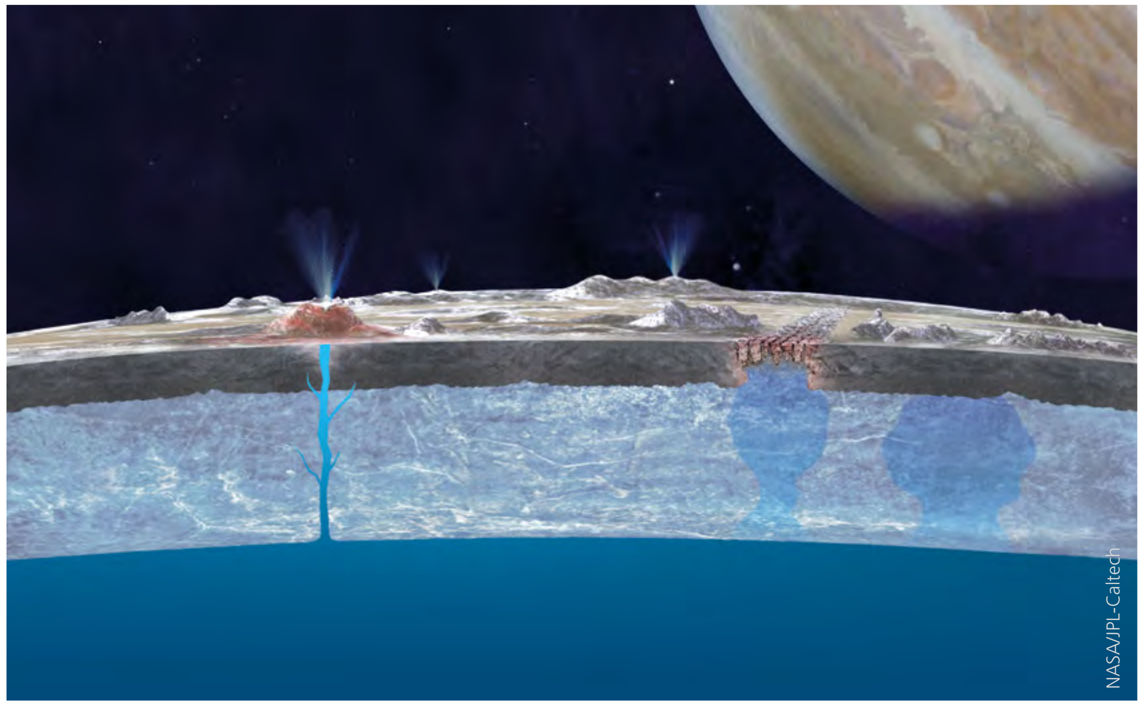
JUICE will conduct detailed studies of Jupiter and its system in the 2030s. The focus of the mission is to find out how these potentially life-friendly environments formed under the icy crusts of the gas giant's moons, and what they look like today. The focus is on the hidden seas of Ganymede and Europa, and possibly also Callisto. As a quasi-planetary body and a potential habitat, Ganymede will undergo the most detailed study. It is a great laboratory for analysing the nature, evolution and potential habitability of icy worlds. It is also of interest due to its unique magnetic field and plasma interactions with the Jupiter environment. Investigations of Europa and Callisto will complete the investigation. Jupiter itself is the archetype for the gas giants of the Solar System and therefore also for the thousands of giant exoplanets now known to orbit other stars.

**A winding path through space**

But these events are a long way off. The ESA spacecraft is currently being prepared in Toulouse, at Airbus Defence and Space, for its launch on an Ariane 5 rocket in the autumn of 2022. The instruments have already been put through their paces and calibrated, have received the demanding spaceworthiness certification, and are currently being installed on the spacecraft. The journey through space to Jupiter, whose orbit is located approximately 780 million kilometres from the Sun, is expected to take almost eight years, and will require four flybys of Earth and one of Venus. Finally, the JUICE spacecraft will spend eight months orbiting Ganymede, during which it will make detailed investigations of the moon and its surroundings, and will eventually impact on the surface.

**Ulrich Köhler** is a planetary geologist at the DLR Institute of Planetary Research in Berlin-Adlershof. He has fond memories of the arrival of NASA's Galileo space probe at Jupiter in 1995.


NASA/JPL/DLR


NASA/JPL-Caltech

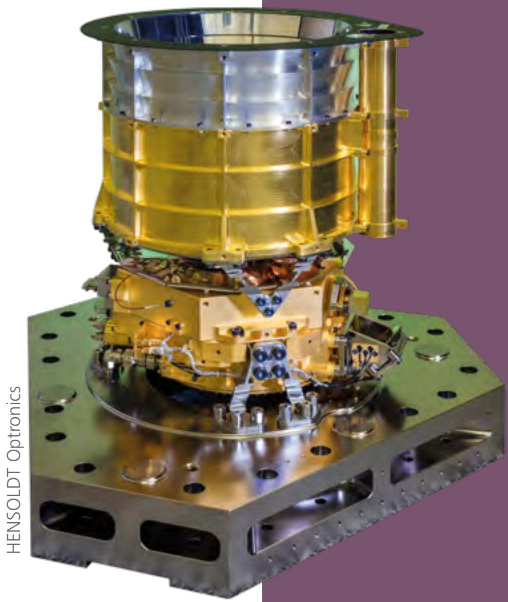
Broken, displaced and rotated ice blocks, partly covered by coloured mineral salts (top image), are clear evidence of an ocean beneath Europa's ice crust (right image). From the latter, salty water is forced onto the surface, where it freezes and reacts with sulphur from volcanic eruptions on Io.

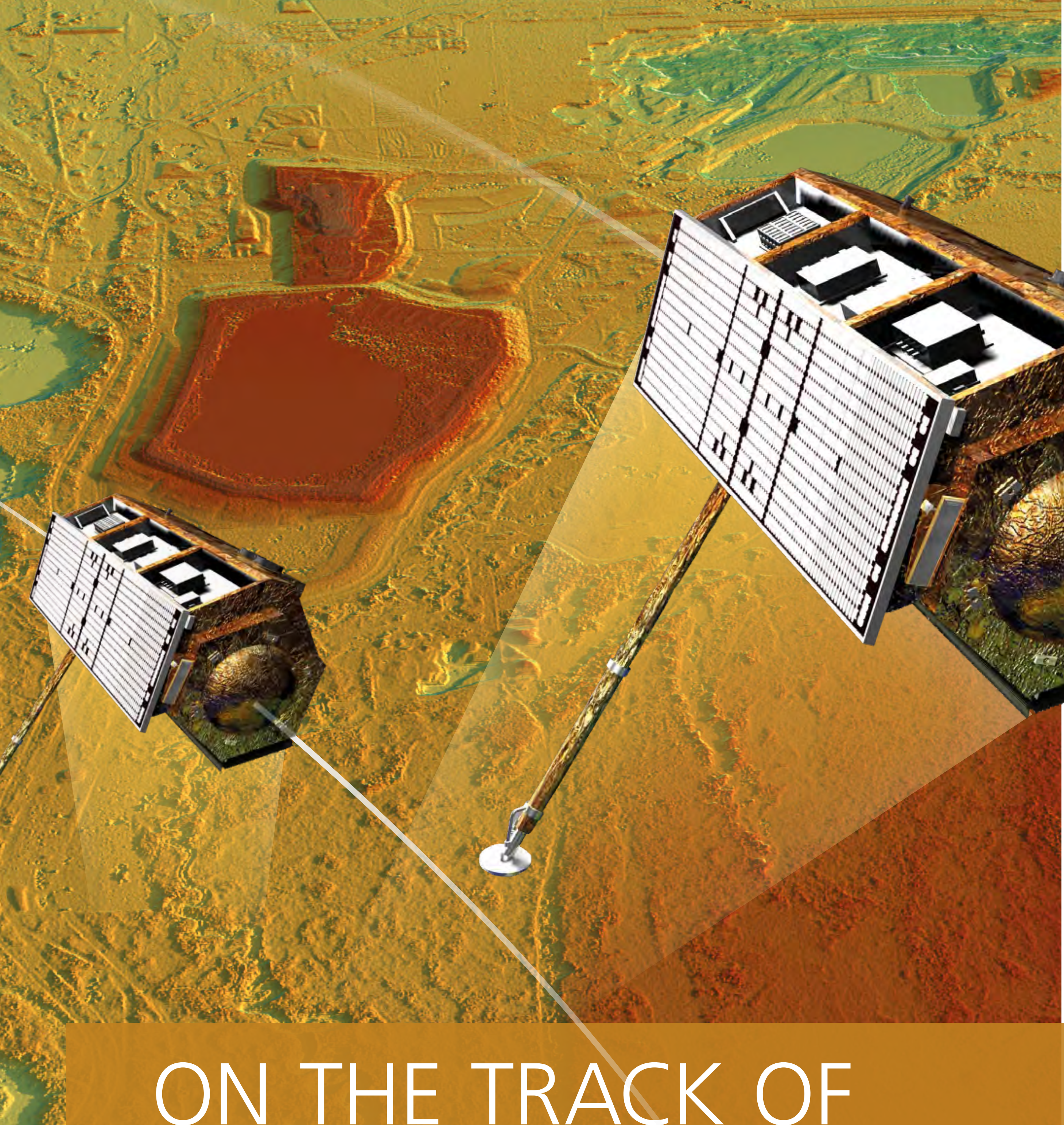
## GALA

The Ganymede Laser Altimeter (GALA) was developed under the responsibility of the DLR Institute of Planetary Research and was built in cooperation with industrial partners (HENSOLDT Optronics GmbH, Oberkochen) and research institutions from Germany, Japan, Switzerland and Spain. This is the first time that such an instrument will be used in the outer Solar System. The Principal Investigator is Hauke Hußmann of the DLR Institute of Planetary Research.

GALA will measure the tidal deformation of Ganymede's ice crust, and thereby its shape, to provide possible clues to the existence of a planet-wide inner ocean. In addition, an extensive map of the entire regional and local topography of Ganymede will be created, which should help us understand the processes that formed this moon. Tidal deformations will be determined from measurements made at different times during Ganymede's seven-day orbit around Jupiter. The height of the tidal deformation can be used to prove the existence of the inner ocean and to determine the mechanical properties of the ice layer above it. The experiment will also record measurements for Europa and Callisto. It is hoped that observations of Europa will yield evidence for the existence of liquid water just below the surface.

GALA consists of two electronic units and an optical part, which contains the laser and the telescope for the receiver. Laser pulses in the near infrared are sent 30 to 50 times per second from a height of 500 kilometres to the surface of Ganymede to make altitude measurements. A highly sensitive detector then records the reflected pulses. Because GALA can measure the time of flight with an accuracy of less than a nanosecond, the position and alignment of the probe can be determined with great certainty, and Ganymede's surface can thus be scanned at a very high optical resolution. The data will be used to produce a global elevation model.


HENSOLDT Optronics



# ON THE TRACK OF GLOBAL CHANGE

## A new digital elevation model provided by the TanDEM-X satellite duo shows how Earth's surface is changing

By Manfred Zink

**The TanDEM-X radar satellite heralded a new era in radar remote sensing. Since its launch in 2010, it has been orbiting Earth in close formation with its 'twin', TerraSAR-X, which went into orbit three years earlier. Together, they acquire data for elevation models of the entire planet. These models provide an indispensable foundation for commercial applications and scientific research. Earlier elevation models, created from multiple data sources and different survey methods, gave only an approximate, inconsistent or incomplete picture for large parts of the world. The TanDEM-X mission changed this with its Digital Elevation Model (DEM) of the entire Earth's landmass in uniform quality and unprecedented accuracy. But for the DLR researchers, this was just the beginning.**

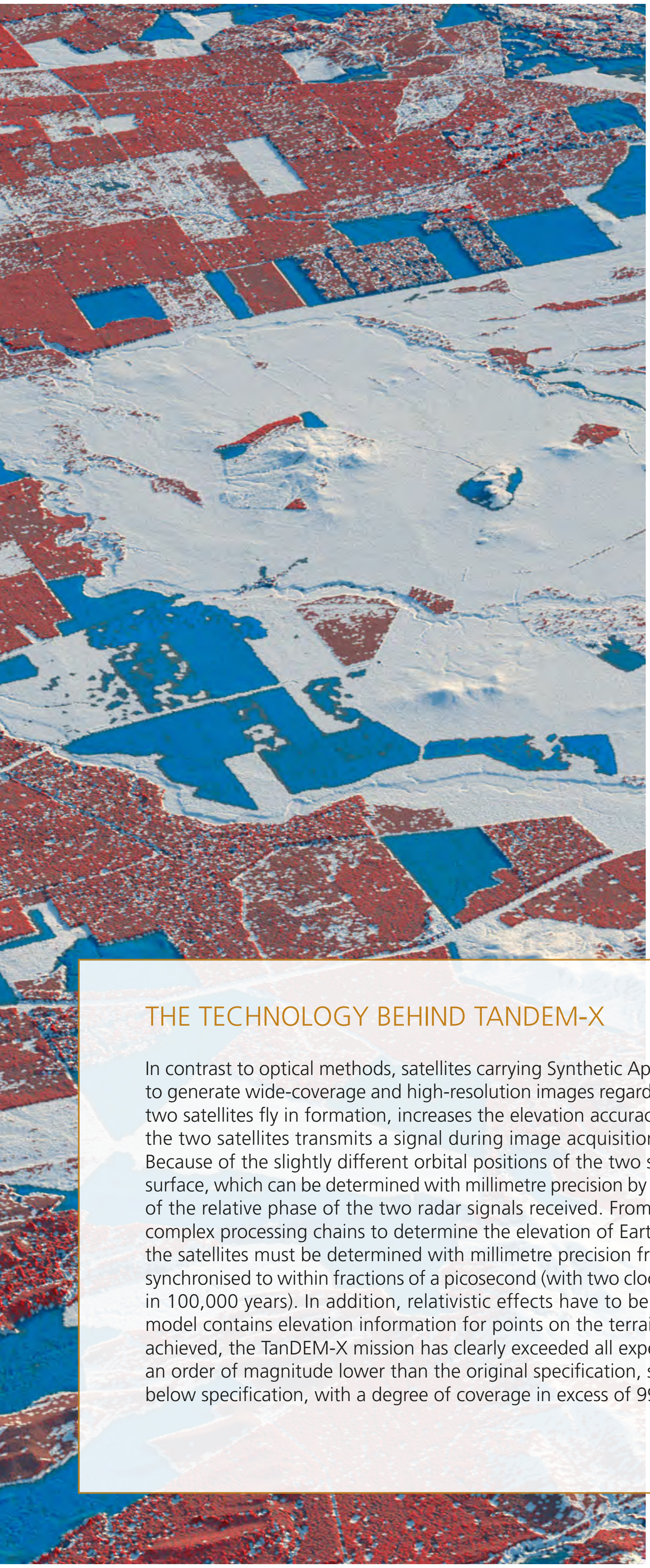
Since the completion of the DEM in 2016, more than 4000 researchers from 97 countries have put its elevation data to use. The focus is naturally on the geosciences such as geology, glaciology, oceanography and hydrology, but the data have also been invaluable to users concerned with vegetation monitoring, environmental protection, land use, city and infrastructure planning, cartography and crisis management. Everyone working in these fields can access the extensive datasets and evaluate them according to their needs. TanDEM-X is the first formation-flying radar interferometer in space. Flying in formation at a distance between the two satellites that varies from several kilometres to as little as 120 metres, depending on the mission phase, the sensors are able to obtain a three-dimensional view of Earth's surface. In this way, the structure of the terrain can be captured with a single overflight. To date, the system is still unique worldwide.

**Human activity and global changes**

While working on the first model, it became clear to the DLR researchers that the elevation accuracy of TanDEM-X was so high that even changes within a year could be recorded. The analyses conducted revealed that Earth's surface is highly dynamic – changes in the height of glaciers, permafrost areas and forests were expected, but changes due to agricultural activities and infrastructure projects also leave clear traces and can be measured. Observing these processes and determining them quantitatively is not only of great interest for science, but also has socio-political relevance with regard to climate change. For this reason, in 2017 the decision was made to continue the mission with a focus on topographical changes.

By 2020, the two German satellites had mapped Earth's entire landmass one more time as the basis for an updated elevation model, the TanDEM-X DEM 2020. Researchers can now compare this second data set with the first DEM version and evaluate the changes over time. In addition to anthropogenic changes, in opencast mines or larger infrastructure projects for example, the first results show, above all, dramatic developments such as the melting of glaciers and ice sheets and the uncontrolled deforestation of tropical forests.

Glacier tongues on the south-eastern edge of Vatnajökull, the largest glacier area in Iceland. Up to 40 metres of elevation change due to melting was measured over the blue-coloured areas between 2012 and 2017.



### From snapshots to time series

By repeatedly observing certain areas, a time series of data is created. The dataset gradually grows and, in addition to the three spatial dimensions, goes on to have a fourth dimension – time – revealing new, previously hidden findings. While the TanDEM-X DEM 2020 data set allows a one-time comparison between two time periods and, in a sense, is a snapshot of events on a global level, repeated recordings of particular focus areas give a more detailed picture. For example, the growth and degradation of forests can be measured. Repeated height measurements also allow the observation and quantification of the melting of glaciers and ice sheets caused by global warming. Never before have Greenland and Antarctica been surveyed so comprehensively and with such a high degree of accuracy in three dimensions.

Both satellites have now significantly exceeded their five-and-a-half year design lifetime. After 11 and 14 years of operation, their radar systems remain in excellent condition and are still fully functional and absolutely stable. They continue to deliver reliable, high-quality radar data. At the moment, their fuel reserves and battery capacities are expected to allow their operation for several more years without serious limitations.

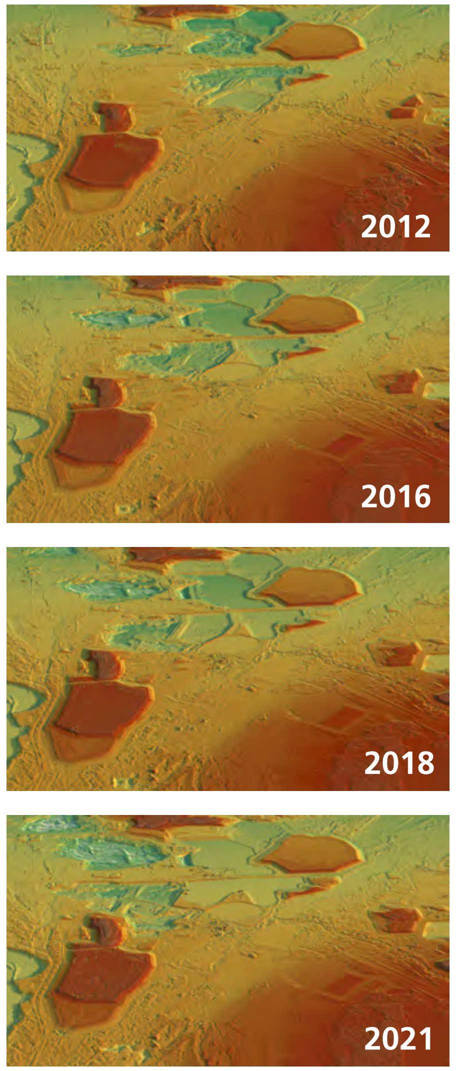
### When two become four

At the outset, the TanDEM-X team did not plan on capturing these dynamic processes. The added value of the mission has, however, continued to increase as it has progressed. In particular, the interferometric acquisitions in formation flight provide information that sets the TanDEM-X mission apart from all other Earth observation missions. The temporal component of the selected focus areas of Earth's surface generates unique datasets and makes a valuable contribution to socio-politically relevant topics such as climate change, which are becoming increasingly important with time.

## THE TECHNOLOGY BEHIND TANDEM-X

In contrast to optical methods, satellites carrying Synthetic Aperture Radar (SAR) technology have the advantage of being able to generate wide-coverage and high-resolution images regardless of cloud cover and sunlight. Bistatic interferometry, in which two satellites fly in formation, increases the elevation accuracy compared to conventional stereoscopic methods. Only one of the two satellites transmits a signal during image acquisition, while both receive the signals reflected from Earth's surface. Because of the slightly different orbital positions of the two satellites there is a difference in distance to any point on Earth's surface, which can be determined with millimetre precision by means of interferometry, a technique based on the measurement of the relative phase of the two radar signals received. From these data, scientists working in the DLR ground segment use complex processing chains to determine the elevation of Earth's surface. Extreme precision is required; the distance between the satellites must be determined with millimetre precision from GPS receiver measurements, and the radar systems must be synchronised to within fractions of a picosecond (with two clocks, this corresponds to a difference of approximately one second in 100,000 years). In addition, relativistic effects have to be considered. The result is a Digital Elevation Model (DEM). The model contains elevation information for points on the terrain in a regular grid of 12 by 12 metres. In terms of the accuracy achieved, the TanDEM-X mission has clearly exceeded all expectations. The absolute height error is approximately one metre, an order of magnitude lower than the original specification, set at 10 metres. The number of gaps in the data set is also well below specification, with a degree of coverage in excess of 99.89 percent.

This image, east of Lake Taupo on New Zealand's North Island, shows the change in elevation with respect to the global TanDEM-X DEM for data recorded in 2019. In the intensively managed forest, the elevation has decreased in the areas marked in blue by up to 35 metres due to logging, but significant growth, in the order of several metres, can be seen in the red areas. With knowledge of the tree species growing there, changes in height can be used to determine changes in biomass and contributions to the carbon dioxide balance.




Time series of elevation models in the area of the Athabasca Oil Sands in northeast Alberta, Canada. DEMs from 2012, 2016, 2018 and 2021 show the dramatic progress of oil extraction from one of the largest oil sands deposits in the world.

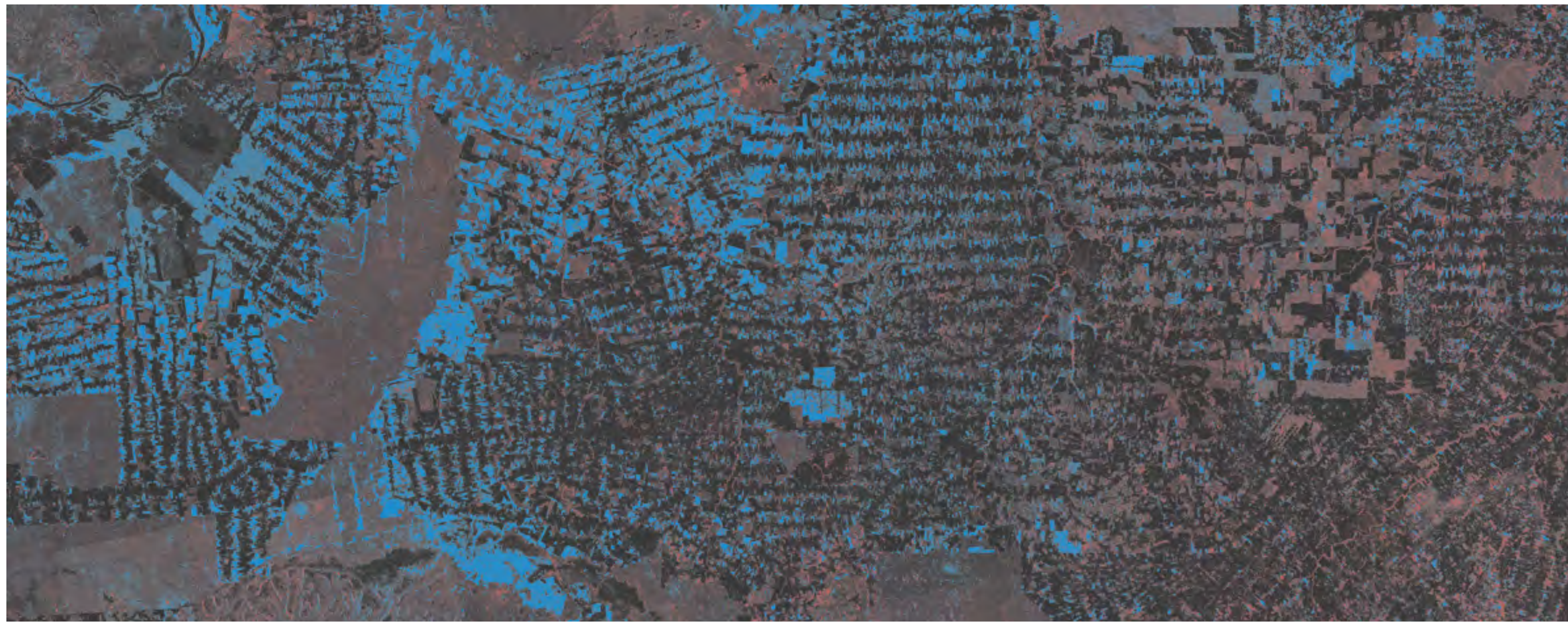
## DATA ON THE WEB

In addition to the full-resolution 12-metre grid, the TanDEM-X elevation models are also available with lower-resolution grids of 30 and 90 metres. The 12- and 30-metre variants are available to researchers through an application process at DLR (tandemx-science.dlr.de). The 90-metre variant is freely available for scientific purposes after simple registration.

**geoservice.DLR.de**

Looking to the future, the team hopes to build on the success of TanDEM-X with the mission proposal 'High Resolution Wide Swath' (HRWS). This system will be based on four satellites – a main satellite that transmits radar signals in X-band, and three smaller satellites, referred to as MirrorSAR satellites, which only receive the signals reflected from Earth. The combination of these three measurements will enable the generation of significantly more precise and finer elevation models, and will make it possible to deliver digital terrain models of every region of the world, on request, with only a short lead time. Meanwhile, the team is constantly expanding TanDEM-X's image of Earth. Step by step the TanDEM-X DEM 2020 and a map of global changes are being created. In the years to come, researchers will focus on global 3D observation of the cryosphere, forests and large cities and thus document the constant changes that are occurring.

**Manfred Zink** heads the Satellite SAR Systems department at the DLR Microwaves and Radar Institute in Oberpfaffenhofen. He has been involved in the TanDEM-X mission since 2005.

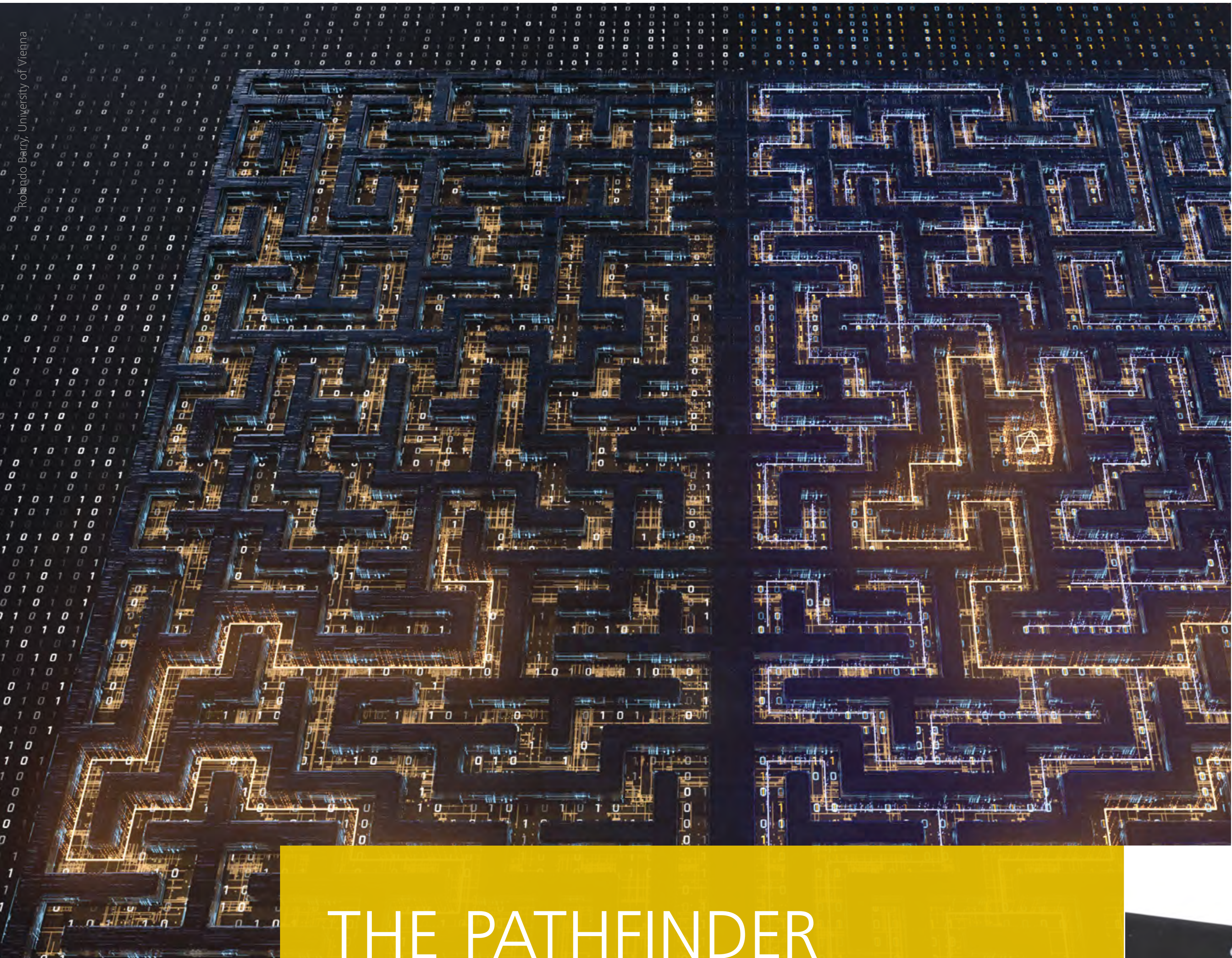


Elevation change map (period 2011/12 and 2018/19) for an area in the 'Arc of Deforestation' in the Brazilian state of Rondônia. The areas marked in blue show ongoing deforestation of the rainforest.

# FULLY MIRRORED

Solar tower power plants use arrays of thousands of mirrors to reflect sunlight onto a radiation receiver at the top of a tower. This receiver then converts the solar radiation into heat, which is used to produce steam to drive a turbine generator that delivers electricity. Surplus heat is transferred into a thermal energy storage system, which releases it when demand increases. The tower power plants use tubular radiation receivers with molten salt as the heat transfer medium. State-of-the art central receivers heat the molten salt up to 565 degrees Celsius. However, the heliostat field of a solar tower can generate significantly higher temperatures.

Starting next spring, researchers from the DLR Institute of Solar Research, alongside partners from industry, will be testing a new tubular radiation receiver using molten salt at the multifocus tower (left) in Jülich. The new receiver can withstand temperatures of up to 600 degrees Celsius and is intended to increase the performance of solar power plants. The Institute's experimental solar power plant can be seen to the right of the multifocus tower.



Rolando Barry, University of Vienna

Machine learning can be compared to trying out and memorising paths through a maze. The challenge is to accelerate this learning, and this is where quantum physics can help.

# THE PATHFINDER

## Sabine Wölk teaches algorithms to learn – with quanta

By Jens Mende

**Learning from experience is commonplace for humans, but less so for machines. Today's computers can recognise patterns, images and speech, and using artificial intelligence, they can solve tasks independently. However, classical computing reaches its limits when these processes become too complex. Quantum algorithms are the basis of a new form of machine learning, which enables previously unattainable computing power and efficiency. DLR researchers have their eyes on novel applications, including data and information processing, the domains of Industry 4.0, robotics, financial services, logistics, as well as medicine and healthcare. Sabine Wölk is one of the scientists involved, working at the DLR Institute of Quantum Technologies. As part of an international research team, she recently demonstrated that a quantum learning algorithm is faster than its classical counterpart.**

**Computers, machines and robots can now learn and solve tasks that could previously only be mastered with human intelligence. Does this form of artificial intelligence function in the same way as human learning?**

: Indeed, there are similarities. We learn by constantly restructuring our brains through stimuli and experience. Abstract thinking and remembering objects and events allow us to, for example, recognise and categorise patterns and situations. We expand our knowledge through independent thought, which also allows us to solve tasks we may never have encountered before based on previous experience.

Machine learning is based on computer algorithms. These are mathematical calculation rules that initially map input values to output values in a very strict manner. In reinforcement learning, an algorithm independently develops strategies to solve tasks, trying out different solutions and actions. When these are successful, the computer remembers them and, armed with this accumulated knowledge, new unfamiliar tasks can be solved, provided that they bear enough similarity to previous successfully performed exercises.

**How can a computer be taught this knowledge?**

: As with people, practice makes perfect! To do this, the learning algorithms must first process many similar tasks and solve them successfully. Let's take an activity as simple as peeling potatoes. We can all recognise a potato – its exact shape and size are not important. This makes peeling the potato easy for us – but not for a machine. If all potatoes were the same shape and size, a machine would be able to peel them far more precisely than we can, as the same process would have been carried out repeatedly.


© DLR

### SABINE WÖLK ...

... is a theoretical physicist at the DLR Institute of Quantum Technologies in Ulm. She researches quantum algorithms for accelerated machine learning. In 2011 she obtained her doctorate, which involved the factorisation of numbers with the help of quantum algorithms. Sabine undertook a one-year research fellowship at the A&M University in Texas. She then worked at the Universities of Siegen and Innsbruck on the theoretical aspects of the development of quantum computers based on ion traps and quantum algorithms for accelerated machine learning. Dr Wölk has been working at DLR since 2019.

## MACHINE LEARNING IS ...

... a sub-field of artificial intelligence. It enables machines to solve tasks independently and to execute them intelligently. To do this, they imitate human learning. Computer algorithms generate their own knowledge by identifying structures, patterns and similarities in stored data sets. With this experience, the algorithms can then independently make predictions and take target-oriented decisions without having been explicitly programmed to do so. Success and failure in solving new tasks constantly refine and build on this knowledge. Typical applications of machine learning are speech and image recognition, data mining, recommendation systems, autonomous vehicles and robotics.

However, it is not so easy with real potatoes. Their sheer variety makes it impossible to program a machine in advance for all possible potato shapes and sizes. Nevertheless, a computer can be trained to do it. Let's say the cut potato peel is too thick – the learning algorithm could store a bad value for this. For thinner peels, a good value would be generated.

**What is the biggest challenge in machine learning?**

**:** The more difficult and complex a task is, the longer it takes for the learning algorithm to find a solution to it. Computers usually need hundreds of attempts at learning to even recognise simple patterns. The current challenge is therefore to accelerate their training rate.

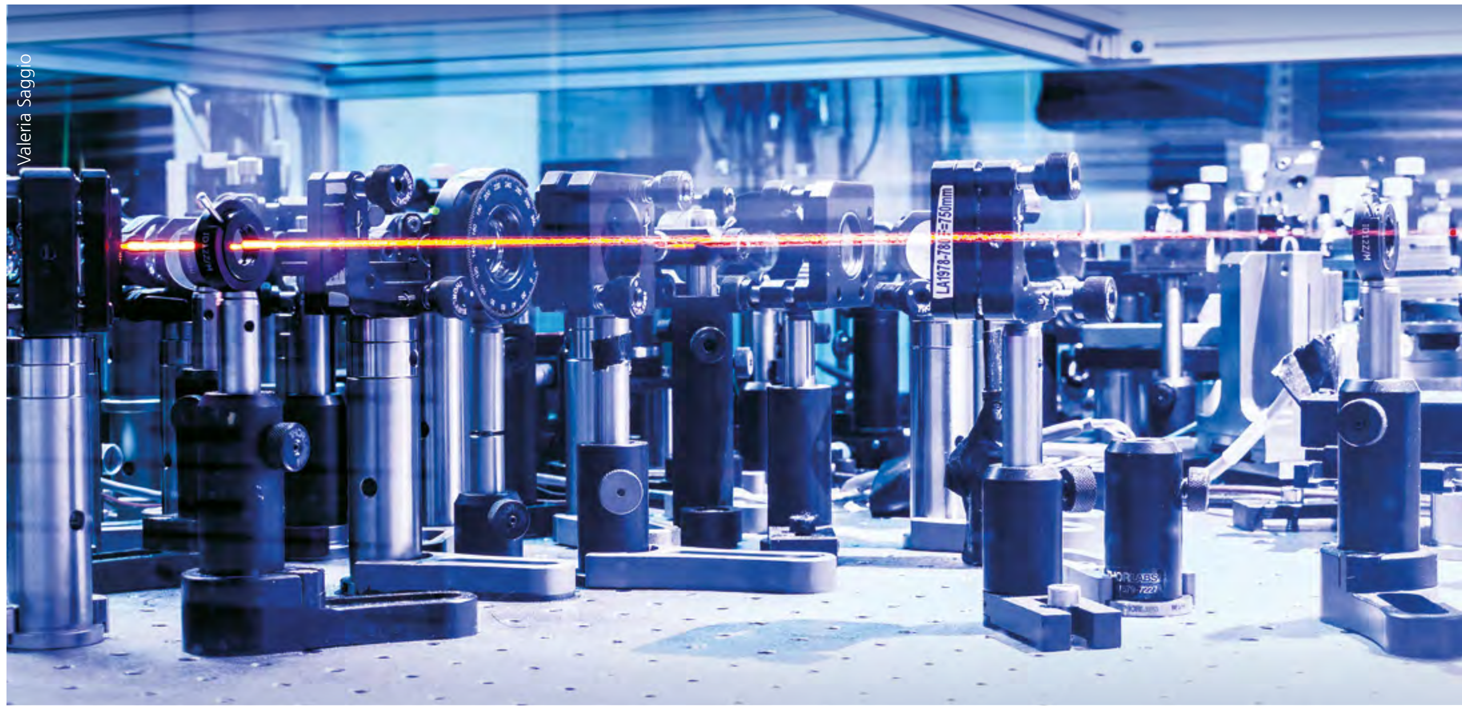
Again, take a simple example: Suppose you are looking for your way to a destination in a city you have never visited before. You have neither a city map nor a navigation app on your phone. At the beginning, you might randomly decide on a path at each intersection. At some point, you will get where you wanted to go, although it is highly unlikely to have been along the shortest route. Next time, however, you will already know your way around, and you will start by taking streets that you know are leading in the right direction. Every now and then you might take a new, unexplored turn. In this way you will find other, even shorter routes to your destination. The bigger the city, the longer the search will take, and if there are too many paths, you won't be able to walk them all. This corresponds to a calculation method in which classic computers reach their limits. This where quantum physics can come into play. If you were a quantum physical particle, you would be able to go both left and right at every intersection at the same time, allowing you to try several different routes simultaneously. This property is the decisive advantage of quantum algorithms.

**Quantum physics can accelerate machine learning – how can this be proven in a laboratory setting?**

**:** Algorithms can be simulated with optical components. These structures are composed of mirrors, lenses, beam splitters or waveguides which modulate rays of light to represent the calculation steps in an algorithm. Photons – the light particles – carry the information to be processed. Depending on how the optical elements are arranged and adjusted, different computing operations can be mapped.

In our experiment, the result of the calculation is encoded in the path the photon took through the apparatus. It took several routes simultaneously. One way to imagine it is as if the photon expanded like a cloud over the apparatus. We are able to show this by means of interference, characteristic brightness patterns with a structure resembling overlapping water waves. In classical algorithm modelling, the photon can only take a single path in each run of the experiment and no interference occurs.

With our project partners at the universities of Innsbruck, Leiden and Vienna, we used a waveguide chip from the Massachusetts Institute of Technology to show that a quantum algorithm requires fewer computational steps than its classical counterpart. The computing time of this classical algorithm increased quadratically with the complexity of the task, while that of our quantum algorithm increased in a linear fashion. This means that the quantum algorithm only needs two calculation steps instead of four, 10 instead of 100 or 1000 instead of a million, resulting in an incredibly effective process.




Quantum algorithms are more effective than classical algorithms. Scientists have successfully proven this in a laboratory test with light particles (photons).

**Where can this enormous efficiency be used? How far apart are the quantum world, machine learning and our everyday lives?**

**:** Machine learning using quantum algorithms is still mainly fundamental research, and we are currently working on the principles of its feasibility. We are creating capabilities that will be extremely helpful for future applications. One long-term goal, for example, is independent robotics. There are countless applications for such processes in industry, business, mobility and the environment, up to and including medicine and healthcare.

**What are the next steps in this visionary future?**

**:** Quantum-based machine learning has not yet left the laboratory. Our team is working together with other DLR institutes to develop and optimise quantum algorithms and hardware. The aim is to use quantum technologies to solve highly complex, application-oriented tasks, such as the electrochemical processes that take place in batteries and fuel cells on the atomic scale. With the help of quantum computers, we hope to simulate these microscopic processes very precisely. By understanding processes on the atomic scale, we aim to modify materials in a specific manner to improve their macroscopic properties. With the DLR Institute of Engineering Thermodynamics, we are working on increasing the electrical output and energy density of batteries. Here too, quantum algorithms are unmatched.

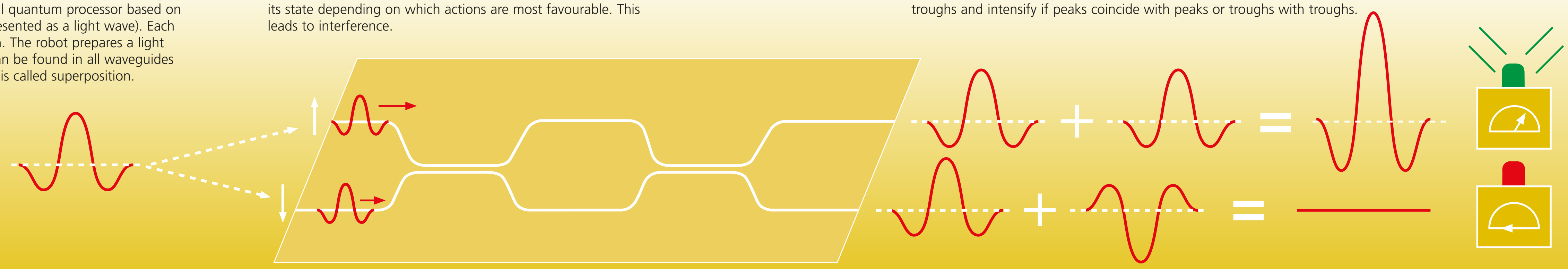
**Jens Mende** is responsible for communications at the DLR site in Stuttgart.

A robot wants to know which action is best: to go up or go down. To decide, it uses a small quantum processor based on waveguides and photons (represented as a light wave). Each waveguide stands for an action. The robot prepares a light photon in such a way that it can be found in all waveguides with the same probability. This is called superposition.

The photon passes through the quantum processor and changes its state depending on which actions are most favourable. This leads to interference.

As with water waves, light waves cancel each other out if peaks meet troughs and intensify if peaks coincide with peaks or troughs with troughs.

In the end, the highest probability is that the photon will be detected in the light guide that indicates the most favourable action. In this example, the correct action is to 'go up'.



Mexico City after the severe earthquake in September 2017

# EVERY MINUTE COUNTS

## DLR supports the aid organisation I.S.A.R. Germany in its humanitarian aid missions

By Melanie-Konstanze Wiese

**Following disasters, such as the floods in Rhineland-Palatinate and North Rhine-Westphalia in Germany in the summer of 2021, the earthquake that shook Mexico in 2017 or the devastating explosion in Beirut in 2020, emergency forces must be able to intervene quickly. DLR has been cooperating with the aid organisation International Search-and-Rescue (I.S.A.R.) Germany since 2016. As part of this cooperation, the partners are testing new technologies for the rapid mapping and assessment of emergency situations during international disaster relief operations. With its technical expertise and specially trained personnel, the DLR Institute of Optical Sensor Systems supports I.S.A.R. Germany in its research and development cooperation activities for crisis and disaster management. And that's not all. The many different kinds of relief missions place special demands on the technology, which have to be taken into account as early as the development stage. For scientists at DLR, this means that technologies born in the laboratory must be ready to be deployed in real-world situations.**

### Tailored technology

During emergency situations, often only a few critical hours are available to make key decisions, such as who will take part in an operation. In parallel, the required technology must be quickly deployable and easily transportable. For these reasons, the team from the DLR Institute of Optical Sensor Systems in Berlin developed its Modular Aerial Camera System (MACS) to be operated on small uncrewed aerial vehicles (UAVs, better known as drones). A member of the MACS family was created especially for humanitarian aid missions. Its name: MACS-Micro. The scientists integrated the compact camera variant into a Vertical Take-Off and Landing (VTOL) drone that can be operated at 80 kilometres per hour for up to 90 minutes. Its ability to take-off and land vertically provides a clear advantage for relief efforts, as the runway is moved up into the air.

© DLR

DLR researcher Matthias Geßner with the VTOL drone. The lens of the MACS camera, which can be seen near the centre, is built into the drone.



"All the mission equipment – drone, camera and ground station – fits into a 1.8- metre-long box that weighs approximately 25 kilograms, making it absolutely suitable for travel," says Ralf Berger, Head of the Security Research and Applications department at the Institute. "In addition, depending on the situation, we can support missions with additional equipment, such as small drones for local exploration."

With the camera system, high-resolution maps of the area can be created in real time or immediately after landing. "In this way, we can map major incidents from the air within a few minutes and make this information available immediately to the emergency services on site," explains Berger. Unknown situations can thus be explored much more rapidly and safely.


### On standby 24/7

Disaster aid is a full time job. Ralf Berger's team has to keep all the equipment in working condition at all times, because when the call comes from an aid organisation, time is already running out. For the same reason, well-trained staff form an essential element of the cooperation with I.S.A.R. Germany. This team includes three experienced researchers from the Institute of Optical Sensor Systems to accompany these aid missions as drone pilots. "They not only bring the technical expertise from their respective fields such as mechanical engineering, surveying, geoinformation and computer science with them, but are also particularly committed to humanitarian causes," reports Berger. All team members are trained and certified drone pilots and have been I.S.A.R. Germany volunteers for several years.

### I.S.A.R. Germany

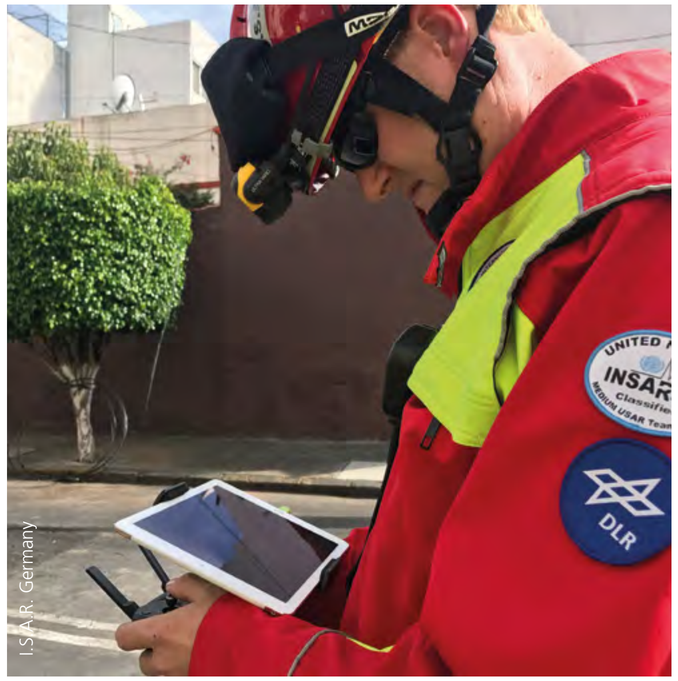
The non-profit aid organisation was founded in Duisburg in 2003. It carries out rescue missions worldwide. Specialists from various aid organisations and the German Federal Rescue Dog Association have come together in I.S.A.R. Germany along with around 170 helpers, most of whom work on a voluntary basis. A small staff takes care of organisation, member support and donations. I.S.A.R. Germany has worked under the umbrella of the United Nations since 2007.

Here, experience should not be underestimated. "Thanks to many previous measurement campaigns with our MACS camera systems – often in remote areas of the world such as Nepal, Greenland or Alaska – we know what is important during such operations. We have to remain calm and be able to improvise, especially when situations change unexpectedly." Every mission is different, but all of them involve arriving at the site as quickly as possible and managing without external infrastructure such as electricity, water, food or shelter. Even getting there can be made more difficult if roads have been destroyed. The DLR pilot is responsible for getting the mission equipment into and out of the mission area safely and undamaged. On site, they must be able to work independently under the disaster conditions, while efficiently using their own and local resources. At the same time, they have to communicate with the teams of other organisations and coordinate the joint work as it progresses. Linguistic and bureaucratic barriers can present additional challenges.

### Well-trained and closely accompanied

Experience, technical knowledge and personal commitment are the prerequisites for every helping hand – and are all immensely important for the work of non-governmental relief organisations. In addition, it is important to be prepared for extreme situations that are not part of the researchers' daily routines. Therefore, regular training and medical check-ups are essential. The team also frequently run a number of scenarios. When a disaster strikes, each member of I.S.A.R. Germany can give the others support, going over what they have experienced. Professional colleagues from the fire brigades, police, military and relief services as well as from the fields of medicine, psychology and obstetrics are therefore always part of the response team.

**Melanie-Konstanze Wiese** is is responsible for communications at DLR's Berlin, Neustrelitz, Jena, Dresden, Cottbus and Zittau sites.



I.S.A.R. Germany

On site, the pilot controls the drone with the help of a tablet. The image data from the MACS camera is processed in real time and visualised immediately.

Adobe Stock

# CITIES, PEOPLE, FUTURE

Strategies for the city life of tomorrow are being developed and tested across Germany as part of the Smart Cities Model Projects initiative

By Dorothee Fricke

**How can cities and municipalities become both more sustainable and more liveable thanks to digitalisation? This is the question posed by 'Smart Cities Model Projects', an initiative involving 73 cities, municipalities and municipal associations. The projects are funded by Germany's Federal Ministry of the Interior, Building and Community. Since September 2021, a Coordination and Transfer Office (KTS) under the direction of the DLR Project Management Agency has been providing advice and support. Matthias Woiwode von Gilardi heads the KTS. The graduate urban planner has been working in the field of European and international cooperation at the DLR Project Management Agency for many years. Michael Ortgiese from the DLR Institute of Transportation Systems in Berlin, which is also involved in the KTS, focuses his research on the integration of new digital solutions for the management of traffic and mobility. Here, the two talk about what it is that makes a city smart and about what is important now.**

**How would you define the Smart City?**

IHK Berlin

Michael Ortgiese

**Ortgiese:** As a citizen, I'd be particularly interested in smart communications with the administration, although it is worth remembering that 'smart' is not always synonymous with digital! Smart cities use the potential offered by digitalisation and the exchange of data to rethink processes.

**Woiwode von Gilardi:** For me there's no such thing as 'the' Smart City – every city or region has its own characteristics, which makes each Smart City concept different and individual. It's not just about technological advances, but also social innovations. As a citizen of a Smart City, I will find it simple to indicate the areas where I would like to see improvements. I might be involved in planning processes for city districts, or in decisions about investments in public infrastructure.

**What are the greatest challenges for cities and municipalities on the road to becoming a Smart City?**

Private

Matthias Woiwode von Gilardi

**Woiwode von Gilardi:** First of all, they will need models and objectives, which have to be developed together with the citizens and all stakeholders in a community. To make this a reality, we need better processes to more holistically organise public administration, building and housing, and energy and transport. On this basis we should use digital technologies that can help to upgrade the 'urban operating system'.

**Ortgiese:** The challenge is not simply to digitalise everything, but rather to think fundamentally about how we would like to work together in the future. If the Smart City strategy is not integrated into an overall urban planning strategy, the best-funded project will be of little use, its effects quickly falling by the wayside. We may have a lot of local IT specialists, but they may lack important methodological knowledge of urban and traffic planning – this is something that other co-workers can bring in. The same applies in the opposite direction. Hardly anyone has experience in all relevant fields, so a new, integrative understanding of planning is required.

**What role does the Coordination and Transfer Office (KTS) play in the context of the Model Projects initiative?**

**Woiwode von Gilardi:** We relieve the strain on the model projects when planning and implementing this transformation. We help them to build the capacities necessary and empower them. Our mission is to provide them with a toolbox. To do so we combine the transfer of knowledge, research and evaluation – but above all we focus on very close and individually tailored support for each project. Our vision is to jointly develop an open learning and innovation system – among other things by providing digital and analogue spaces for cooperation, in which German municipalities can, for example, jointly develop urban data platforms and open source solutions. And what is most important: The impact should and will extend beyond the funded municipalities – nationally and internationally.

**Ortgiese:** There are often good solutions already in place on a sectoral basis, but these are not linked. An example is different transport systems in a city which might not be compatible with each other. We want to encourage municipalities to think in new and experimental ways. In this way, the city can grow together with its surrounding area.

## SELECTED MODEL PROJECTS

Stadt Ulm

### ULM – A BETTER QUALITY OF LIFE THROUGH DIGITALISATION

*The city of Ulm has set itself the goal of using the intelligent networking of digital technologies to make everyday life easier for its citizens and to improve their quality of life – such as in the area of security. One example would be stressful environments such as poorly-lit underpasses; how can these be made safer? These spaces can be shown in 3D models, where alternative measures such as smart lighting can be included. The models will also be used to discuss with citizens which alternatives might be implemented.*

Torsten Arnold/Digital Layer: Siemens

### COTTBUS – SELF CHECK-IN AT THE HOSPITAL

*General health services are one of seven fields of activity of the 'Digital City of Cottbus'. Through digitalisation, citizens will benefit from the networking of health care systems and from medical progress. Clinical data and documents are bundled to ensure that both patients and specialist staff have a full overview – for orientation, transparency and convenience. A real-world example of this is the 'self check-in', which started in August 2020 at the Hospital Carl-Thiem-Klinikum in Cottbus. Patients can admit themselves to the clinic using a tablet. This saves waiting time for patients, while the clinic gains staff capacity and processes are streamlined.*

**In addition to the DLR Project Management Agency and the DLR Institute of Transportation Systems, other partners from research, training and consulting are also involved in the Coordination and Transfer Office (KTS). What does this consortium do?**

**Ortgiese:** The KTS represents the scope of Smart Cities. No single institution could ever encompass the Smart Cities concept as a whole.

**Woiwode von Gilardi:** The KTS brings together different schools of thought, various skills and backgrounds of experience, and thus works in an interdisciplinary manner. The institutions involved are both large and small, those that do research and those that are out in the field introducing new methods – in citizen participation, for example. For us as the DLR Project Management Agency, it is incredibly exciting to coordinate such a project and to be able to contribute our competences and experience, such as the management of offices, political and scientific communication, and the monitoring of projects and programmes.

**Dorothee Fricke** works at the DLR Project Management Agency and is responsible for press and public relations at the Coordination and Transfer Office (KTS).

## STRONG PARTNERS TO ANSWER THE QUESTIONS OF THE FUTURE

As the central pillar of the DLR Science, Innovation and Education Management business domain, the DLR Project Management Agency has been supporting various players from the worlds of politics, science, business and education with a wide range of services for more than 40 years. In addition to Smart Cities, it will increasingly be working with DLR institutes focused on other future-oriented topics. "It is about pooling skills and expertise from management, consulting and research," says Roman Noetzel, who heads the Strategy and Monitoring department in the Agency's European and International cooperation division: "This creates a win-win situation for DLR, its customers and society at large." Exchange formats, such as the planned 'Smart City Club' or topic groups for discussing future technologies such as hydrogen or quantum technologies, are intended to help leverage shared potential.

Further information on the Smart Cities project can be found at

**smart-city-dialog.de/en/**


## BERLIN – INTELLIGENTLY NETWORKED IN THE EVENT OF A CRISIS

*Under the motto 'Berlin liveable and smart', Germany's capital is developing a new strategy in which digitalisation and technology can generate social benefits and strengthen the democratic community. Five pilot projects are set to start in 2022. For example, the Kiezbox 2.0 equipment will be installed at selected locations around the city. In the event of a crisis, such as a power failure, Kiezboxes will be used to create an emergency WLAN with solar or battery-powered hotspots, which can keep the local population informed. Even when there is no emergency, the Kiezboxes will be in use – collecting data on the climate or air quality, for example.*


## HAMBURG – DIGITAL TWINS

*In the 'Connected Urban Twins' project, Hamburg, Leipzig and Munich are jointly developing what is known as digital twins. Digital twins are more than just 3D models of a city. Their urban data platforms are continuously fed with fresh information concerning buildings, roads and bodies of water or with real-time data such as climate measurements. This enables simulations and analyses that offer new perspectives for integrated urban planning and participation. Under the leadership of the city of Hamburg, the team is improving existing technologies using only common standards and open source solutions to ensure the availability for other cities.*



# YOUR QUESTIONS ANSWERED

Our researchers answer questions from the community

**Asking questions is key to improving your understanding of how and why things work as they do. Particularly in science, an inquiring approach is indispensable for addressing and better understanding complex topics. We regularly receive questions about a wide range of scientific subjects on our social media channels, by letter or by email. If you too have a question you would like to ask, please contact us at magazin@dlr.de.**

**Question from Berta via Facebook:**

*I would like to know why experiments in microgravity are so important for medicine and materials research. Can you offer an explanation using specific examples?*

Physical, chemical and biological processes take place on Earth under the influence of gravity. For many of these processes, this is a disruptive factor. For example, gravity hinders the production of high-purity crystals, materials and biological tissues. For living organisms, however, gravity is an important environmental factor that they use for orientation and to optimise living conditions. In microgravity, we can remove this environmental factor, study the effects of gravity and often even make targeted use of the lack thereof. On the International Space Station (ISS), for example, various alloys are melted and re-solidified to obtain precise data for modelling purposes. This information helps to improve casting processes, for example to create an extremely light titanium aluminide turbine blade for aircraft engines, or to develop new materials. Gravitational biologists have gained important insights into gravity perception and the gravity-oriented growth of plants and animals. People on Earth benefit greatly from research conducted by astronauts. Answers to the questions of how the human body adapts to microgravity and what countermeasures can be developed for space travellers to maintain health and performance in microgravity can be translated to medical applications on Earth for diagnostics, prevention and treatments. The overall goal is to improve the healthy lifespan of an ageing society.

**Jens Jordan, Head of the DLR Institute of Aerospace Medicine, and Markus Braun, Head of the Space Life Sciences Programme at the German Space Agency at DLR.**

**Question from Ava B.:**

*What is a shooting star?*

Every day, several billion pieces of metallic materials or rock from outer space hit Earth's atmosphere. Collectively, they weigh about as much as a large and fully loaded truck. Fortunately, most of these arrivals are not much bigger than a speck of dust. But due to their extremely high speed on their journey through the atmosphere, they can ionise the air through friction causing the surrounding air to glow. At night, when it is dark and the sky is clear, the trails of these falling objects appear as shooting stars.

**Christoph Pawek, Head of the DLR_School_Lab Berlin**

**In issue number 168, there was an error in the answer to the question '… does space eventually come to an end?' The answer suggested that Einstein's General Theory of Relativity states that 'this motion [the galaxies moving away from one another] causes 'time dilation' and that this is noticeable as a shift in the wavelength of observed visible light from far-away objects towards the infrared portion of the electromagnetic spectrum. However, solutions to the field equations of this theory imply a (possibly accelerated) expansion of space, that is, a 'dilation' of the spatial coordinates alone and not of time or of 'space-time' in general. This expansion of space is then observed as the red shift of the light from distant cosmic objects. Thanks to Günter Volknant.*

# FROM THE ARCHIVE

**This section follows a fascinating trail of discovery through the DLR Central Archive. The second article in the series features a group of divers who travelled to extreme depths at a DLR institute more than 30 years ago – all this without ever going underwater.**


Arrival: Frank Weist (front right) and the other two test divers in the TITAN chamber make it to a depth of 615 metres. The photo was taken from the outside, through one of the portholes.

# DEEP DIVING ON DRY LAND

## An extraordinary feat in the TITAN pressure chamber

By Katja Lenz

**615 metres. The three young divers that reached this depth hold up a sign for photographers on 1 May 1990. It would be four weeks before they were to see sunlight and breathe fresh air again. This record-breaking dive was carried out more than 30 years ago in the DLR TITAN pressure chamber. Entering the water was never necessary – all that was needed were the technology and steel walls of the baromedical laboratory.**

Inside TITAN it was possible to create extreme pressure and breathing gas conditions, such as those found at depths of over 600 metres in the North Sea. The use of professional divers for offshore natural gas and oil operations was a hot topic for research at the time. Would it be possible for humans to work on the ocean floor? How would they cope with the extreme pressure conditions? The TITAN chamber and scientists in the then DLR Institute of Aviation Medicine provided a safe, controlled environment for answering these questions.

"We monitored everything around the clock. It was clear to everyone that we had a great responsibility," says Manfred Schulze (57), one of the technicians who worked on the project. For 40 days and nights, the 'chamber operators' sat at the metre-long control and measurement console. The large control dials, buttons and screens can still be found at the DLR Institute of Aerospace Medicine. Dedicated voice communication systems allowed the team to discuss the tests and their results with the three divers – and every now and then chat about everyday things.

However, as the simulated depth increased, communication became more difficult. The breathing gas used was heliox – a mixture of oxygen and helium – the ratio of which the DLR team continuously adapted to the changing pressure conditions. When diving, helium serves as a substitute for nitrogen, which can cause narcosis at the pressures found in deep dives. However, helium changes the voice, so that it turns into a series of incomprehensible squeaks. "From pressures of around 10 bar at a depth of 100 metres, voice distortion is so strong that divers can no longer communicate with each other verbally," says Frank Weist (60). He was the young diver who held the sign on the twelfth day in the chamber. Communication with the DLR team then took place via an electronic equaliser. Peering into and out of the chamber was possible through a small porthole. So why not simply hold up a piece of paper with information written on it? "Well, beyond 500 metres, our hands were rather shaky," says Weist, reminiscing. Simply picking up a pen and paper was an enormous effort. At a depth of over 600 metres all he wanted was to "sit and breathe, and do nothing else."

**The adaptability of the human body is remarkable**

If divers ascend too quickly, the nitrogen will form small bubbles in their blood vessels and tissue as the water pressure decreases. That is why a suitable decompression rate is vital. The DLR team calculated a decompression time of 28 days for the 615-metre TITAN dive. During this time, the three participants had plenty of tasks to keep them busy, including concentration and performance tests, as well as exercises involving dexterity and balance. Cleaning was also on the schedule – hygiene was extremely important in this environment with its high temperature, pressure and humidity. Any infection or injury would have been a disaster. "We couldn't simply evacuate the three divers," says diving master Harry Hebborn (83), who was part of the DLR team. "Bringing in a doctor would have taken days as well."


The driving and measuring stand next to the pressure chamber. DLR's previous name can still be seen: DFVLR stands for German Test and Research Institute for Aviation and Space Flight.

The TITAN pressure chamber is 2.20 metres in diameter and is 6.60 metres long including a wash basin, shower and toilet. From the outside it looks like a spaceship surrounded by measuring devices, pipes and cables. It can accommodate a total of four people. Harry Hebborn and project manager Norbert Luks (69) participated in the selection of the test participants. The most important requirements in addition to their diving experience were their ability to withstand the psychological stress and to get along well with one another. Meals were passed into the chamber through an airlock. Under the extreme pressure, large greasy spots would form on sausages or cheese in seconds. Meat became hard, while puffy desserts arrived as an unappetising mush. "The participants' sense of taste also disappeared," recalls Norbert Luks.

The dive yielded a wealth of scientific knowledge. "It has been proven that the ability of humans to adapt to extreme environmental conditions is considerable," said a DLR announcement at the time. This is no longer an issue on oil rigs. "Deep-sea operations are now carried out by robots. Back then, however, that was not a possibility," says Luks. The TITAN pressure chamber has not been used for deep dives since 1991, when research funding ended. Since then, work has concentrated on the effects of changes in pressure and atmosphere, for example in aerospace, on mountaineering expeditions and train journeys.

**Katja Lenz** is a Media Relations editor at DLR.


From left: Master diver Harry Hebborn, project manager Norbert Luks and chamber operator Manfred Schulze.

### THE HYPERBARIC CHAMBER

The TITAN deep diving simulation facility was commissioned for operation in 1984. It is part of the equipment in the baromedical laboratory at today's DLR Institute for Aerospace Medicine in Cologne. Diving tests were theoretically possible up to a depth of 1000 metres using the chamber. Pressure ranges between five millibar and 70 bar could be generated within it. This corresponds to the range between a light vacuum and a depth of 700 metres underwater.

# COSMIC SPIRITUALITY

## A visit to the Tom Sachs exhibition in the Deichtorhallen Hamburg

By Jana Hoidis

**The Deichtorhallen Hamburg is known for its internationally renowned contemporary art and photography exhibitions. These days, however, they are hosting an entirely different kind of adventure. Tom Sachs is presenting his 'Space Program: Rare Earths' – an opportunity for humans to explore distant celestial bodies. In the Hall for Contemporary Art, visitors can embark on a mission to asteroid Vesta (albeit a fictional one). History, research, vision and spirituality are all artistically woven together in this otherworldly exhibition.**


Henning Rogge/Deichtorhallen Hamburg

Before visitors even arrive at the ticket desk, the artist is there to welcome them, life sized, on a LED screen. Behind it, the first exhibits await. A NASA research vehicle and some astronaut 'welcome' visitors on their journey to space. The path continues into the 300-square-metre exhibition hall. The largest exhibit, containing the landing module, immediately catches the visitors' eye. The resemblance to the Lunar Excursion Module (LEM), later called the Lunar Module (LM), in use during the United States' Apollo Program, is uncanny. In the exhibition guide, you can read that it is in fact a 1:1 model of that lander. Almost everything is engineered from plywood, duct tape and hot glue. This time, however, the landing module is on the asteroid Vesta, not on the Moon. But more on that later...

**Become a member of the mission team through indoctrination**

To fully immerse themselves in the exhibition, visitors are invited to undergo an 'indoctrination' process at the beginning. This takes place in a separate area, right by the entrance to the large hall. It costs an additional five euros. The experience begins immediately after a short queue. You will spend a little time in the waiting area, filling out a questionnaire about yourself and the details of the exhibition. Next, you will be asked to sort a pile of screws, in a mechanics' version of the fairy tale Cinderella: "The good into the pot, the bad into the crop." This monotonous activity is meant to cleanse the mind in a state of catharsis, to make participants receptive to what is to come. After a short conversation about their hand-held devices and social media consumption habits, participants receive a badge and are declared 'indoctrinated'. As you make your way through the exhibition, you will discover that some exhibits can only be accessed using this badge.

**Why asteroid Vesta?**

With his current exhibition, Tom Sachs hopes to raise awareness of today's 'addiction' to hand-held devices and the depletion of raw materials associated with it. Vesta remains pristine. Scientists suspect rare earth elements, gold and copper exist in large quantities inside the asteroid. In the large hall, next to the landing module, boreholes have been drawn on Vesta. It seems someone was looking for raw materials and rare earth elements here.

In addition to the large exhibition area, visitors can explore exhibits on a variety of topics in the smaller rooms. The Museum of the Moon is dedicated to bizarre sculptures related to the Moon landing. The 'Re-Education Center' showcases a film about Tom Sachs' methods in cinematic format. Here, Sachs explains in an entertaining way how his main material, plywood, is processed. His passion for screws resurfaces here as well.

**The Holy Trinity**

Religious rituals are referenced repeatedly throughout the exhibition. In the main hall, for example, you will see a demonstration of the Japanese tea ceremony. The 'VAB' is set up in the middle of the large hall. The abbreviation stands for Vehicle Assembly Building, the real-life version of which houses one of the largest enclosed spaces in the world, where the Saturn V rockets used for the Moon landings were assembled vertically. The VAB in the Deichtorhallen is exactly the opposite – a tiny little room that can be accessed using your badge. Inside you will find nothing but darkness and a floating mini version of Yoda (from the Star Wars saga), before which you can kneel on a prayer bench. Yoda, and elements of the tea ceremony, appear as details in several of the exhibits. Do they symbolise religion? Are they meant to point to a trinity of past, future and spirituality?

As the tour comes to an end, the indoctrinated will be encouraged to 'supplicate themselves' to the act of transubstantiation. Although visiting this areas is also possible for the 'indoctrinated', it is not recommended. The door to transubstantiation is activated with your badge.

DEICHTORHALLEN HAMBURG – CONTEMPORARY ART

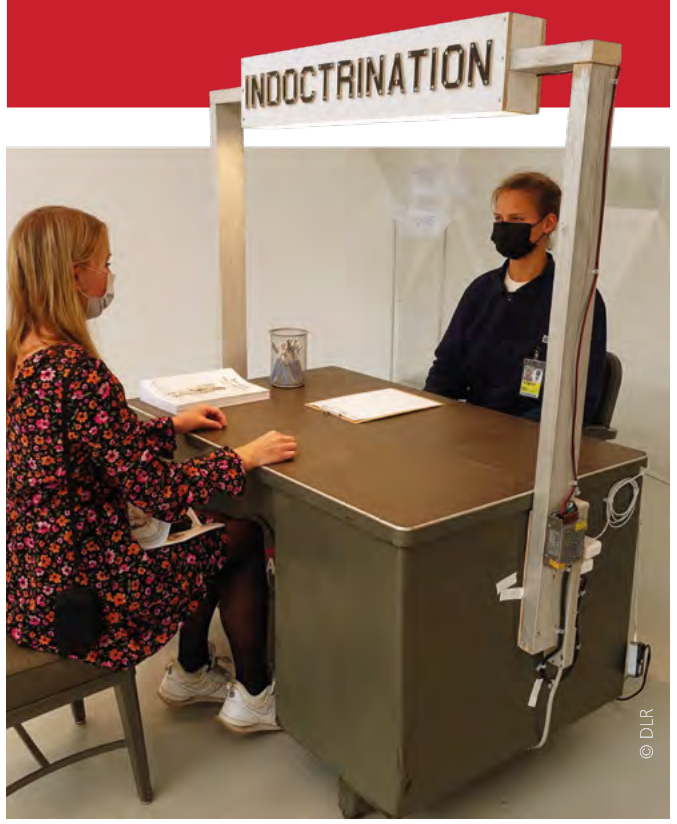
Deichtorstrasse 1–2, Hamburg

Exhibition SPACE PROGRAM – RARE EARTHS until 10 April 2022

**deichtorhallen.de/en/ausstellung/tom-sachs**

Price:
12 euro, reduced rate 7 euro,
children and adolescents free of charge

Opening hours:
Tuesday to Sunday 11:00 to 18:00 CET,
closed on Mondays




© DLR

As if entering a clean room, you will be blasted by a stream of air in order to make sure no dirt particles enter with you … or is it really a spiritual cleanse? At the end you even have the opportunity to lie down inside an MRI machine. Here, everyone should find their place in the Universe.

**Jana Hoidis** is responsible for public relations at DLR's Hamburg site. She has always been a science fiction fan and is excited to see what the future brings.

# REVIEWS

## THE SOUND OF SCIENCE


The story of **Apollo: Atmospheres and Soundtracks** begins in 1979, when young Texas journalist Al Reinert visits the Johnson Space Center. Reinert wants to write an article on the 10th anniversary of the Moon landing, but when he discovers NASA has over 1800 kilometres of unseen footage shot during the Apollo missions, his focus shifts. He decides to watch it all, edit it and turn it into a documentary film. With very little budget and no experience in the movie industry, Reinert asks electronic composer Brian Eno to produce the soundtrack.

Eno, having spent the better part of the previous decade experimenting with sound manipulation, first in the shape of pop songs and later moving into more conceptual compositions, coined the now familiar term 'ambient music' – a new type of background music that invites active listening and scrutiny.

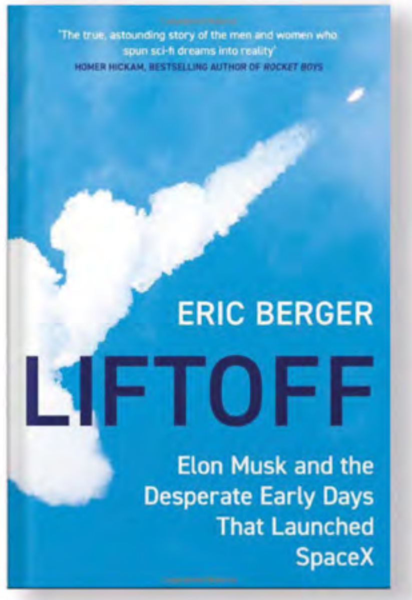
The music contains subtleties and nuances layered over a dark and motionless backdrop. Vast prairies of silence light up with pulsations, whistles and vibrating notes that hang in emptiness, while clusters of sounds arrive and disappear, leaving small rhythmic trails in the distance. Pieces like Signals emanate an eerie, almost menacing aura, while the radiant An Ending (Ascent) provides a genuinely uplifting moment. This is all an acoustic fantasy (after all, in space there is no sound in the traditional sense) that tries to convey the physical effects – the weightlessness and the floating feeling astronauts experience, the sense of stillness despite travelling 40,000 kilometres per hour, the lack of visible boundaries.

Side-B can be considered 'frontier music' for a new frontier. When NASA allowed the Apollo astronauts to carry cassette tapes with their favourite music on board, most of them opted for country tunes. This is where the idea of using the steel guitar to create a version of dilated, psychedelic western music came from. The slow, expanded military march of Deep Blue Day bridges space with the Delta blues, while Weightlessness aims to recreate the classic 'Nashville twang' in microgravity.

After many revisions, the documentary Apollo was released – to critical acclaim – only in 1989, with the title For All Mankind. By that time, Apollo: Atmospheres and Soundtracks had already lived multiple lives of its own, becoming part of our own collective imagination, in a way shaping how space has since been depicted in popular media. Thirty-eight years after its inception, it is still a shortcut to experience an approximation of what the Apollo astronauts felt, through the speakers of our Hi-Fi.

**Simone Morelli**

## LAUNCHING INTO NEW SPACE




No doubt, Elon Musk is a legend. Following a decade without launchers for crewed space missions, NASA is finally able to transport astronauts into space from US soil, all thanks to SpaceX. **Liftoff: Elon Musk and the Desperate Early Days That Launched SpaceX** (Harper Collins Publ. USA) looks back at the initial years of the ambitious company and describes how Elon Musk succeeded in getting rocket science back on the launch pad. Musk is introduced as a man of conviction – meticulous when it comes to development and an entrepreneur through and through.

Author Eric Berger has collected numerous stories, but also presents fundamental insights into the principles that help find new technical solutions. For Musk, for example, mistakes are an opportunity to learn and improve, and technology never stands alone. Liftoff explains, almost preaches, how Musk recruits future employees with such conviction from the very first moment and motivates them again and again. It also becomes clear how demanding the culture at SpaceX is. Berger provides a vivid account of how Musk's grand vision and long-term goals were implemented. In addition, SpaceX has thus also opened the market for New Space. A vital start-up scene, especially in Germany and Europe, including private investors, is revolutionising the industry with microlaunchers, SmallSats and constellations for innovative applications. According to Berger, there is much more to be gained with 'deep tech' than is being risked. A worthwhile read for pure space enthusiasts, Liftoff is recommended to anybody who wants to learn, understand and follow the SpaceX journey, from launch to launch.

**Robert Klarner**

## THE MOON MADETH MAN

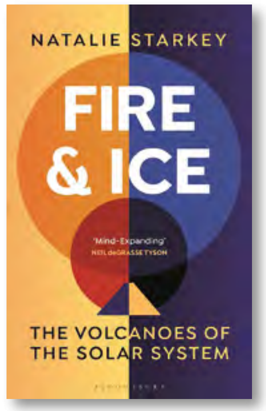

What do you consider the Moon to be? A ball of rock in space, or something more? While we know that it is made of stone and creates the tides, this celestial object has been the focus of countless stories, tales and mythologies. Between its influence on biological and physical processes and on cultures across the globe, Earth's natural satellite has been the object of both study and fascination since the beginning of time.

**The Moon** by Hannah Pang explores the influence of the Moon on humanity, from mythology to science, in a stunning journey illustrated by Thomas Hegbrook. The book is written in easy-to-read sections, peppered with unique art pieces that skilfully reflect the wonder one may feel when looking at the Moon.

This book summarises every way that Earth's natural satellite has influenced our ambitions and cultures. Mythologies, seasons, movies, art, gender, language, medicine, music, science, biology and even architecture each have their moment in the spotlight within these pages. The Moon is so much more than a large stone in the sky, it is, in every sense "the first milestone on the road to the stars."

**Caroline Stadler**

## HOT TOPIC, COOL EXPLANATION




When it comes to geology, I'm dumb as a rock. I know little about the processes that moulded our home planet and eventually paved the way for life to arise. **Fire & Ice: The volcanoes of the Solar System** offers a compelling and comprehensible introduction to one of the most important aspects of planetary geology: volcanism. Natalie Starkey clearly explains the basic concepts of volcanism and planetary geology in general, illustrated using plenty of examples. However, she sets out to do something bigger: to show us that volcanism shapes the history and even the present of most objects in the Solar System. That includes icy worlds such as Pluto, which we long believed to be 'dead'. In particular, the book provides a detailed account of how volcanic phenomena may contribute to the development and survival of life, and not just on Earth.

In that regard, the book may have come a little early. Although space exploration has rapidly advanced our understanding of the Solar System, the study of extraterrestrial volcanism and its consequences seems to be in an early stage. The contrast here is stark: we have a deep understanding of terrestrial volcanism, whereas studying volcanism on other celestial objects seems to involve a lot of scientific guessing based on the limited data and photographs we do have. The book does a good job of allowing us to imagine what such geological and volcanic phenomena would look like on other astronomical bodies. I'm excited to see whether future space missions can confirm some of the interesting theories put forth in this book, understanding that nothing is as of yet set in stone.

**Ruben Walen**

### RECOMMENDED LINKS

ALL ABOARD!
**youtu.be/yHuGHrzwlqE**
Are you a train enthusiast? Are you looking to embark on a different kind of adventure? Fancy going to Norway? Then hop on board! The rail journey from Flåm to Myrdal is considered one of the most beautiful in the world. In this YouTube video, you can join the train driver and watch the entire journey from seaside to mountains, filmed in stunning 4K, from the comfort of your very home.

A GLACIAL MISSION
**s.DLR.de/sxUvW**
Only superlatives can properly describe the sheer magnitude of the Aletsch Glaciers. With a length of over 22 kilometres and a thickness of up to 900 metres, it is the largest glacier in the Alps. In September, a DLR team spent two weeks on the glacier, using a high-resolution camera to take remarkable aerial photos of the dwindling snow masses due to climate change. In this blog, a scientist from the team reports on how the snow cover in this region has changed in recent decades.

A NEW CHANNEL
**www.instagram.com/dlr.en/**
Double the insight, twice the fun. The DLR Instagram channel has split into two. Our new channel is tailored to you, our English-speaking audience, and features stunning visuals, news and more from the world of research at DLR. From experiments on the ISS to ground-breaking research at our institutes across Germany and our work around the globe, get to know us better – follow us on Instagram @dlr.en.

ASK ASTRONAUT MATTHIAS
**s.DLR.de/REhL7**
In this YouTube video series by the German Space Agency at DLR, ESA astronaut Matthias Maurer answers questions about life and work on the International Space Station ISS. The videos usually last about a minute and answer questions about the time on the ISS, how food is swallowed in microgravity, what should be done on the ISS in case of illness, or how astronauts actually make phone calls.

VIDEOS BRING THE WORLD TOGETHER
**trendsreport.withyoutube.com**
In this video, YouTube explains in a visually appealing and easy-to-understand way how the medium of video has developed. For example, the use of live and streaming broadcasts rose sharply during the pandemic. The underlying reason, as Kevin Allocca, who heads YouTube's Culture&Trends department, explains, is that videos create a sense of togetherness. This ranges from joint dance lessons in a livestream to the 'with me' video that invites people to cook, study or even clean together. Exciting insight into the latest trends and the groundwork they are laying for the future.

EXPO 2020
**virtualexpodubai.com**
Travel is a bit complicated these days. If you're looking to learn more about the countries of the world, why not explore the spectacular Expo 2020 Dubai from the comfort of your own home? Until March 2022, visitors can virtually stroll through the campus and visit different locations, such as the Germany Pavilion and the Baden-Württemberg House. Tour the numerous exhibitions and participate in the captivating events to learn more about innovations on the horizon and the progress that has been made so far. Visit Expo2020!

## Cover image

If the volumes of passenger and freight traffic continue to grow, railways can help relieve congestion, because they have enormous potential. Automatic couplings, intelligent freight wagons and fast communications between train sections promise more sustainability, safety and, above all, punctuality. In the Next Generation Train (NGT) project, DLR researchers are developing new concepts for future rail transport. The cover shows the complete NGT train family. NGT Link (left) is an interregional train designed to connect smaller cities with one another and with major urban centres; NGT HST (centre) is a high-speed passenger train that can travel at speeds of up to 400 kilometres per hour; NGT Cargo (right) is a design for an intelligent and automated freight train.

DLR
Deutsches Zentrum
für Luft- und Raumfahrt
German Aerospace Center