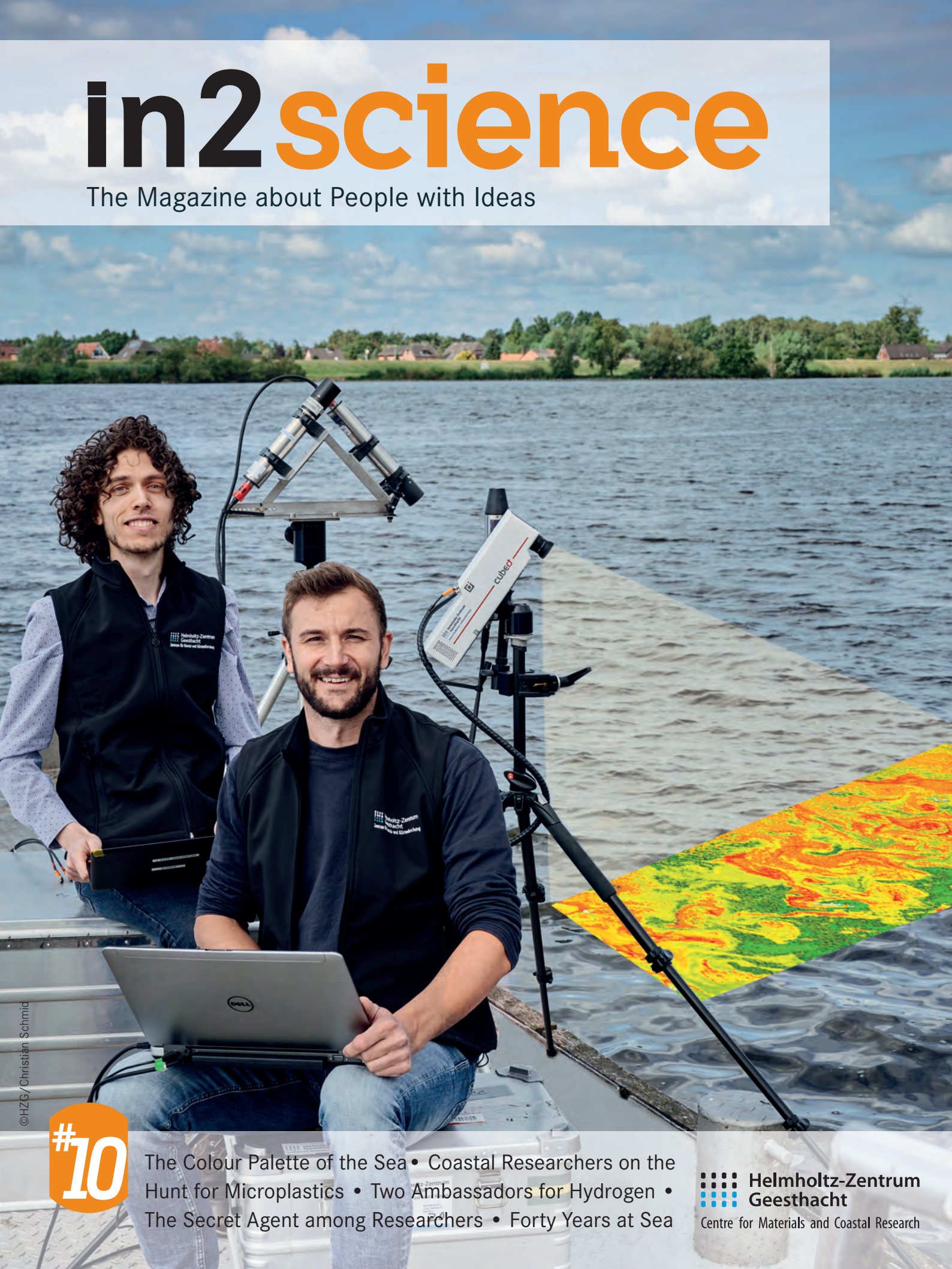
in2science

The Magazine about People with Ideas



©HZG/Christian Schmid

#10

The Colour Palette of the Sea • Coastal Researchers on the Hunt for Microplastics • Two Ambassadors for Hydrogen • The Secret Agent among Researchers • Forty Years at Sea

Helmholtz-Zentrum Geesthacht
Centre for Materials and Coastal Research

Why is Internationality so Important for Research?

With the #BlackLivesMatter movement in focus and in a climate in which some of us question our own national or cultural identities, we would like to set an example as an internationally positioned research centre: The approximately 1,000 employees at our locations and branch offices come from over 55 nations. Research and science can only work in mutual exchange. There is no place for racism and discrimination at HZG.

©HZG/Charleen Schwabe

Dr Giovanni Capurso, Scientist, Nanotechnology

Like in many other human activities (arts, music, cooking, ...) multiculturalism and diversity make our work as researchers more effective, because all of us can just profit from the outlook of colleagues with different backgrounds and expertise acquired in various fields and universities. Something similar happens in material science: in most cases, the properties of an alloy or a composite are improved if more elements and/or phases are mixed together! Science is an expression of human culture and therefore it has to be open and dynamic: internationality is fundamental in research and I am glad HZG welcomes scientists from all over the world.

Ragle Raudsepp, PhD student, Sustainable Energy Technology

©HZG/Christian Schmid

One of the biggest advantages of being a scientist is the opportunity to work with people from different countries all over the world. It does not matter where you come from because in science we all work on similar problems and speak the same language. From HZG I have found myself many friends of different nationalities. I enjoy that every day I do not only learn something new about my research topic but I also learn a lot about different countries, their cultures and also a bit of their language. To me it is a possibility to learn about the world without travelling and I am using it. After finishing my PhD I would like to find a position somewhere with a similar international working environment.

Dr Henry Ovri, Scientist, Experimental Materials Mechanics

©private

I think it is easy to see that internationality is beneficial for research once we all come to terms with the fact that scientifically there is no relationship between skin colour and intellectual abilities. As a minimum then, the pool of intellectual, natural and financial resources needed to solve the complex challenges in our world and correspondingly, the potential to solve these challenges, are significantly increased when knowledge, ideas and collaboration are extended beyond national borders and skin colourations. Moreover, the diversity that each individual brings strengthens rather than weakens research.

Elina Valli, Equal Opportunities Officer of HZG

©HZG/Nicole Thiemann

Our diversity in the working environment is the wealth of the HZG! Well-mixed teams are more dynamic and successful due to different perspectives, knowledge and approaches. As a Finn, I myself have brought Nordic ideas of equality to the HZG. Through friendships with foreign colleagues, we learn about, understand and respect different cultures, ways of life and manners. We benefit from each other! In order to be able to offer all of us at the HZG a corporate culture that is as respectful and as low in conflict as possible, we are currently working on a diversity concept that will help us to positively develop our colleague diversity.

Dear Readers,

2020 – what a year! The corona pandemic turned our lives upside down in one fell swoop. Many HZG scientists also carried out their work from home office. They evaluated data, wrote publications, reviewed literature, drew up proposals. Luckily, some of our colleagues could at times work in the laboratory and at sea by following the applicable health regulations (distancing, hygiene, daily mask wearing) and safety precautions. In this tenth issue of in2science, we're again taking you on a journey through the world of materials, coastal, biomaterials and polymer research.

What colour is the sea? "Blue," is certainly what comes to mind. In our Photo Feature, the coastal researchers show that sea's palette possesses so many more colours and how this is used to address exciting research questions

In June of this year, the federal government finalised the National Hydrogen Strategy. Hamburg Economics Senator Michael Westhagemann and HZG Institute Director Thomas Klassen discuss how well the northern German states are positioned with the technology of the future: hydrogen. Hydrogen will play a huge role in the industrial, transport and energy sectors in the future. Scientists at the HZG are researching climate neutral hydrogen generation and its safe storage in specialised tanks. The new HZG research ship will also be powered by a fuel cell and has now been approved. It's a good time to look back on the forty years of coastal research with the LUDWIG PRANDTL.

When it comes to HZG materials research at the Deutsches Elektronensynchrotron, we often say: "making the invisible visible". But how is this actually done? The infographic at the centre of the issue explores this area. In conjunction with this topic, we present new systems with which the most varying types of samples can be examined.

We also introduce two outstanding individuals in the Portrait sections of the issue: Burkard Baschek, oceanographer and "secret agent" amongst researchers, and Nan Ma, leading scientist in biomaterials research.

We also bring you more exciting topics from Teltow. Polymer materials that can be used as muscles for soft robots; the chance to predict the lifespan of plastics; and individual 3D models of patients' hearts with which minimally invasive procedures can be practiced before surgery. You can experience these biomaterials topics online in 360 degrees and watch video interviews with the researchers.

Our polymer research work has been installed for years now in the "Algae House" in Hamburg: with the help of membranes, carbon dioxide is separated from the gas heating and is used as food for the living façade.

We also report on the detective work the researchers undertake when they're on the hunt for the smallest plastic particles.

Enjoy reading and diving into our research!

Your Editorial Team

We are pleased to present the tenth issue of in2science

A call for submissions:
Employed at the HZG and have an exciting story or outstanding collaboration you'd like to share? Then please get in touch with our editors. We look forward to your ideas, praise and criticism. Simply write to us at in2science@hzg.de

You can subscribe to, read online or download in2science for free here: www.hzg.de/in2science

Imprint

in2science – The Magazine about People with Ideas
Email: In2science@hzg.de

Publisher: Helmholtz-Zentrum Geesthacht
Zentrum für Material und Küstenforschung GmbH
Max-Planck-Str. 1, 21502 Geesthacht
Telephone +49 4152 87 1648, Fax +49 4152 87 1640

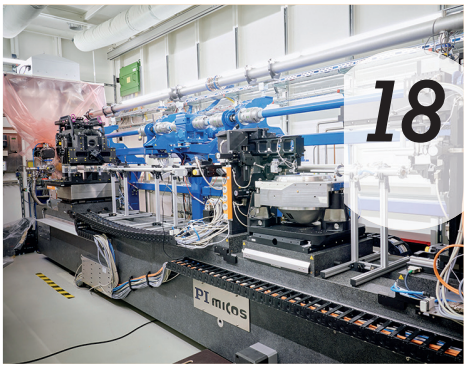
Managing Editors: Gesa Seidel, Heidrun Hillen
Dr Torsten Fischer (ViSdP)

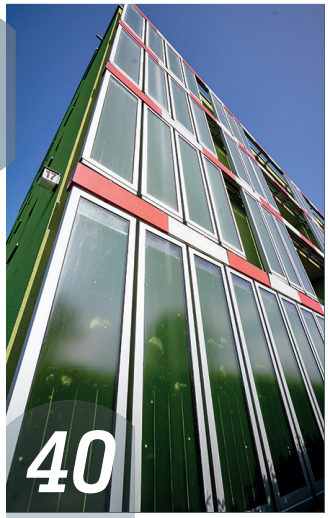
Contributing Editors: Jenny Niederstadt, Frank Grotelüschen, Jochen Metzger

Layout: Bianca Seth

Printing: Helmholtz-Zentrum Geesthacht in-house printing
Paper/ Envirotop (produced from 100% recycled paper, Blue Angel certified [RAL-UZ 14])

January 2021
Circulation: 150





Colourful, not Blue: the Colour Palette of the Sea

Whether a child or artist: water is depicted in blue. Water, however, is colourless. Sometimes lakes, rivers or coastal waters appear rather green, brown, grey, black or even red. Scientists in the Remote Sensing department use the varying colours of water to address exciting research questions, as it is from its colour that certain water properties can be derived. The researchers travel to, on and over the water and take water samples with them to the laboratory. In addition to the "colour" of the water, they measure concentrations of different particulate matter, algae (chlorophyll) and organic degradation products, such as gelbstoff and the optical properties.

Important support in their work is obtained from space. Satellites have been systematically observing the condition of seas and water bodies for approximately forty years: the substance concentrations are derived from what are known as "reflectances". This refers to the ratio of reflected and incident light intensity. Atmospheric influences, which make up the largest portion of the measured signal, must be eliminated. This is known as "atmospheric correction".

A main focus for the researchers is the precise description of the optical properties—that is, absorption and scattering properties as well as reflectivity of the substances in the water. This takes place in the optical laboratory: in defined measurement series, the coastal researchers mix phytoplankton and other substances into the water and measure the light absorption and scattering. The values can be compared with the satellite data and provide information on the quantity, distribution and type of plankton as well as other substances in the sea. Municipal authorities in charge of bathing and drinking water quality also make use of such satellite data, as do fisheries, climate researchers and oceanographers.


JUMBO-BOX

©HZG/Christian Schmid

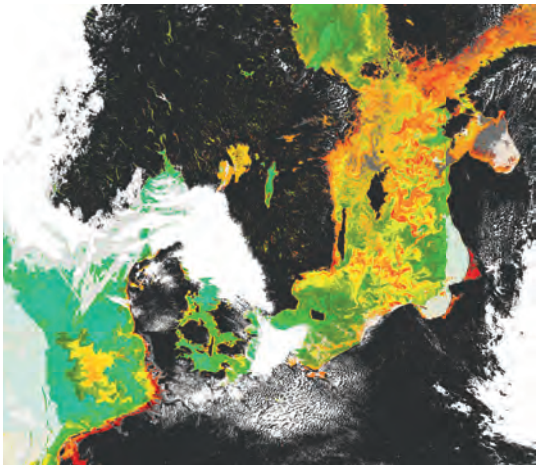
Scattering behaviour and absorption spectrum

The light will scatter and reflect differently depending on the species of algae. In addition, the various types of algae possess characteristic colours: cyanobacteria, green algae, diatoms or dinoflagellates.

Dr Jacopo Agagliate prepares water samples to illuminate them with light of a specific wavelength. This data will be used for radiative transport modelling. In defined measurement series, the researchers mix plankton and other substances into the water and measure the absorption.

Optical fingerprints from varying algae

Approximately half of our oxygen comes from the sea: phytoplankton uses sunlight and carbon dioxide, releasing oxygen during photosynthesis. Algae also form the foundation of the food chain. Some algae, however, produce toxins that can be dangerous for humans and the environment. Determining biomass and differentiating algae species through remote sensing rely mainly on minor differences in spectral absorption characteristics.



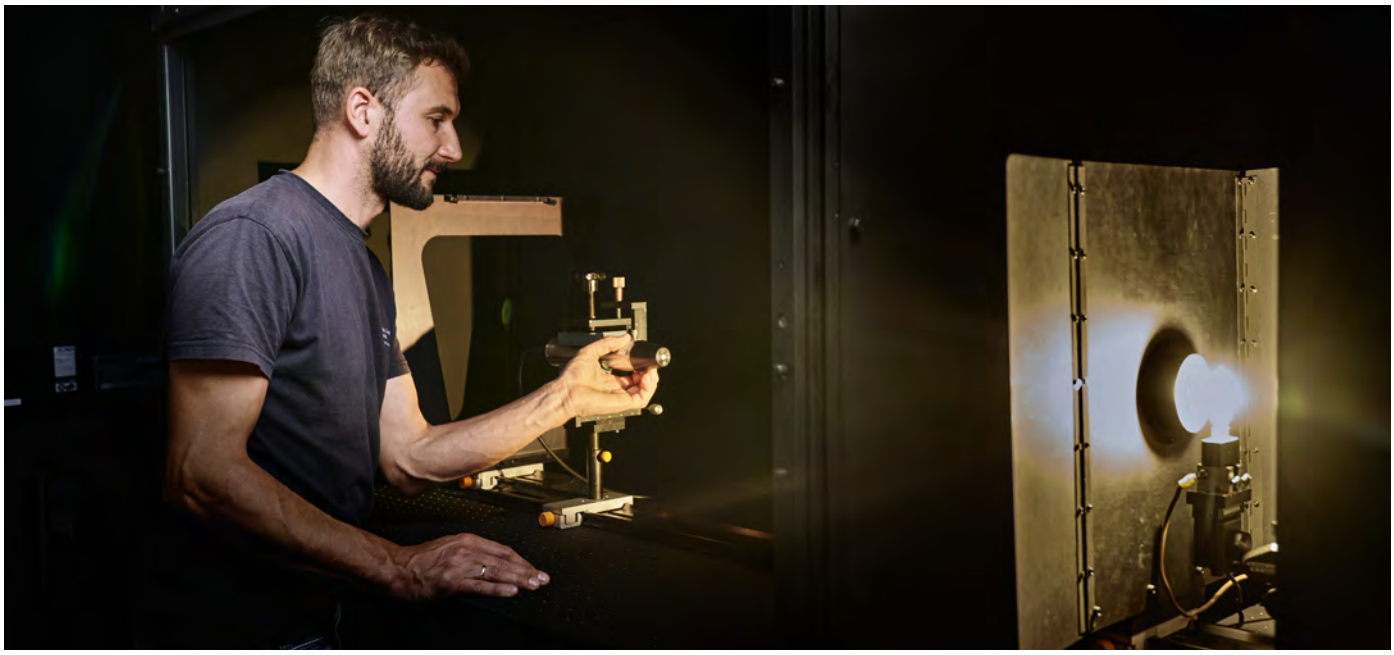
©HZG

The satellite image was taken in July of 2018 by the European Sentinel-3A Ocean and Land Colour Instrument (OLCI) and shows portions of the North and Baltic Seas. The spectral image data are analysed using ocean colour algorithms, and water content such as phytoplankton concentrations in the upper water layers is estimated. At this time of year, blooms of blue-green algae (cyanobacteria) regularly appear in the Baltic Sea, transported by eddy-like ocean currents.

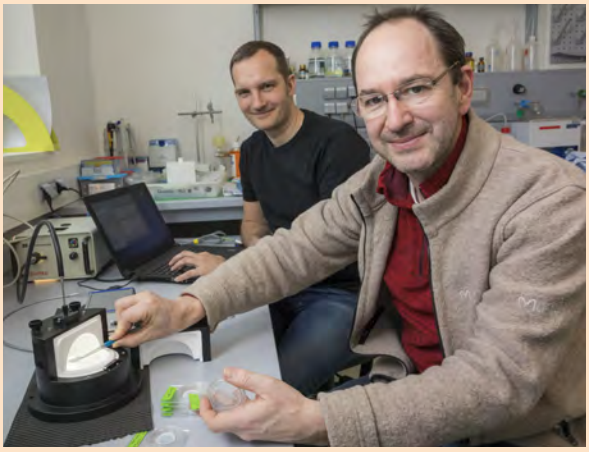
The reason the sea is mostly blue in colour:

Humans can see light in wavelengths between 380 nanometres (violet) and 750 nanometres (red). Unfiltered sunlight in this wavelength range is white. Only when certain wavelengths are removed from this light do colours become visible. When light hits water, a portion of the light is reflected at the surface while another portion penetrates the water and is absorbed and scattered by water particles. The various colours behave differently here. Red light is swallowed by water the fastest; blue light, on the other hand, reaches deep into the water and is scattered back in the upper water layer. If the water is very clear and deep, the blue looks particularly intense.
Dissolved substances, particles or dirt change the colour of the water. Organisms such as plankton, for example, cause the water to appear green; swirled up sand makes the water look yellowish; and dissolved iron and specific species of algae appear red.

The incoming and outgoing light is measured with radiometers. Henning Burmester calibrates the device in the laboratory using a light source.



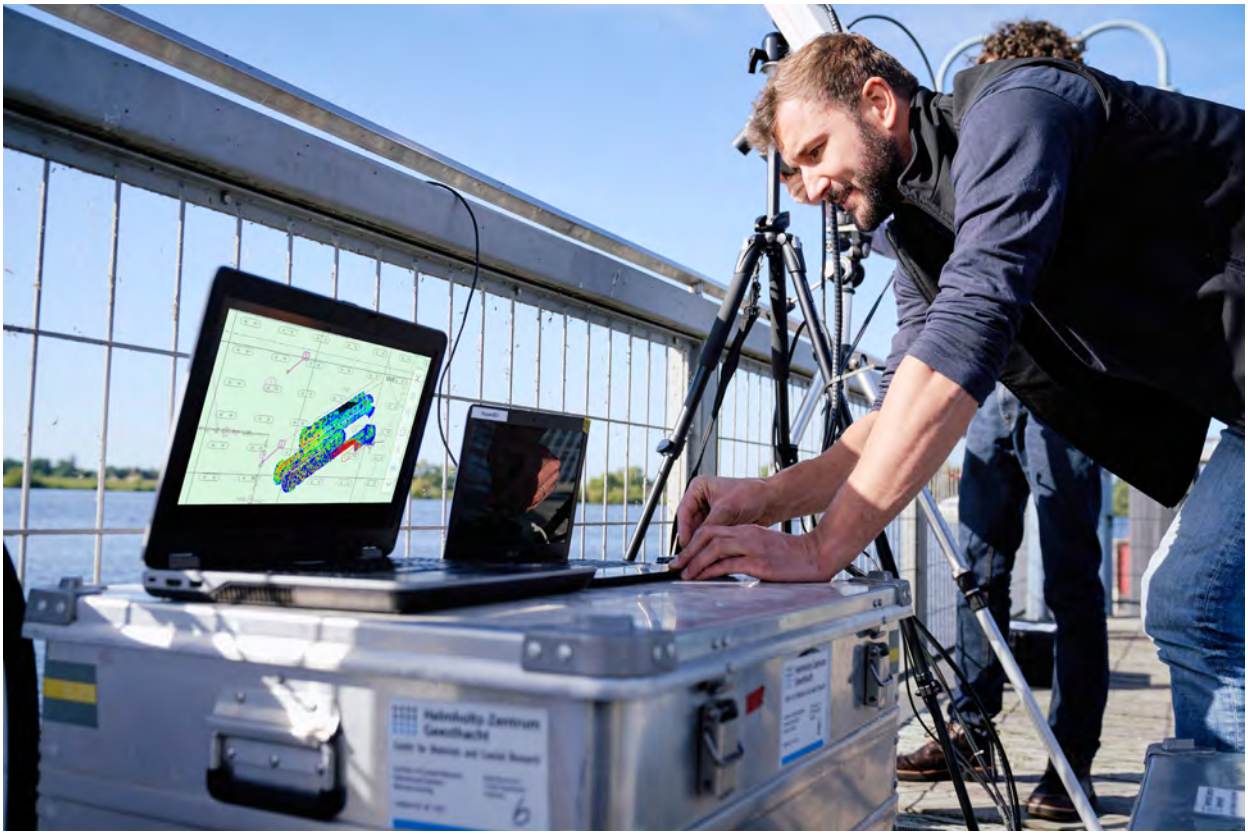
Department head Dr Rüdiger Röttgers (front) and Dr Martin Hieronymi (back) study the water samples in the laboratory. They carry out different absorption and scattering measurements.

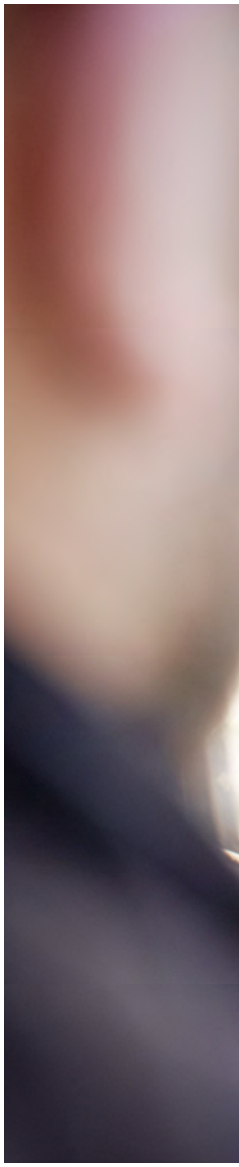


Which algae groups can be differentiated spectrally? Which biomass concentration is necessary to do so? How is the algal detection limited by sediment and dissolved organic substances in inland and coastal waters?
These questions are addressed in the published paper by the Geesthacht coastal scientists: Xi, H., Hieronymi, M., Krasemann, H. & Röttgers, R. (2017). Phytoplankton Group Identification Using Simulated and In situ Hyperspectral Remote Sensing Reflectance. Frontiers in Marine Science.

The Publication:

doi.org/10.3389/fmars.2017.00272





©HZG/Christian Schmid

Measuring from space and from a pier

The camera and radiometer are tested on the Elbe pier near Tesperhude. Henning Burmester checks the data emerging on the monitor. The data will be evaluated only later, with the help of satellite images. Various satellites are in operation and their images are usually taken around noon. With some luck, the scene will be free of clouds, so the team can compare measurement data directly at the water surface, validating the ocean colour algorithms.

A form of sunglasses for sensors

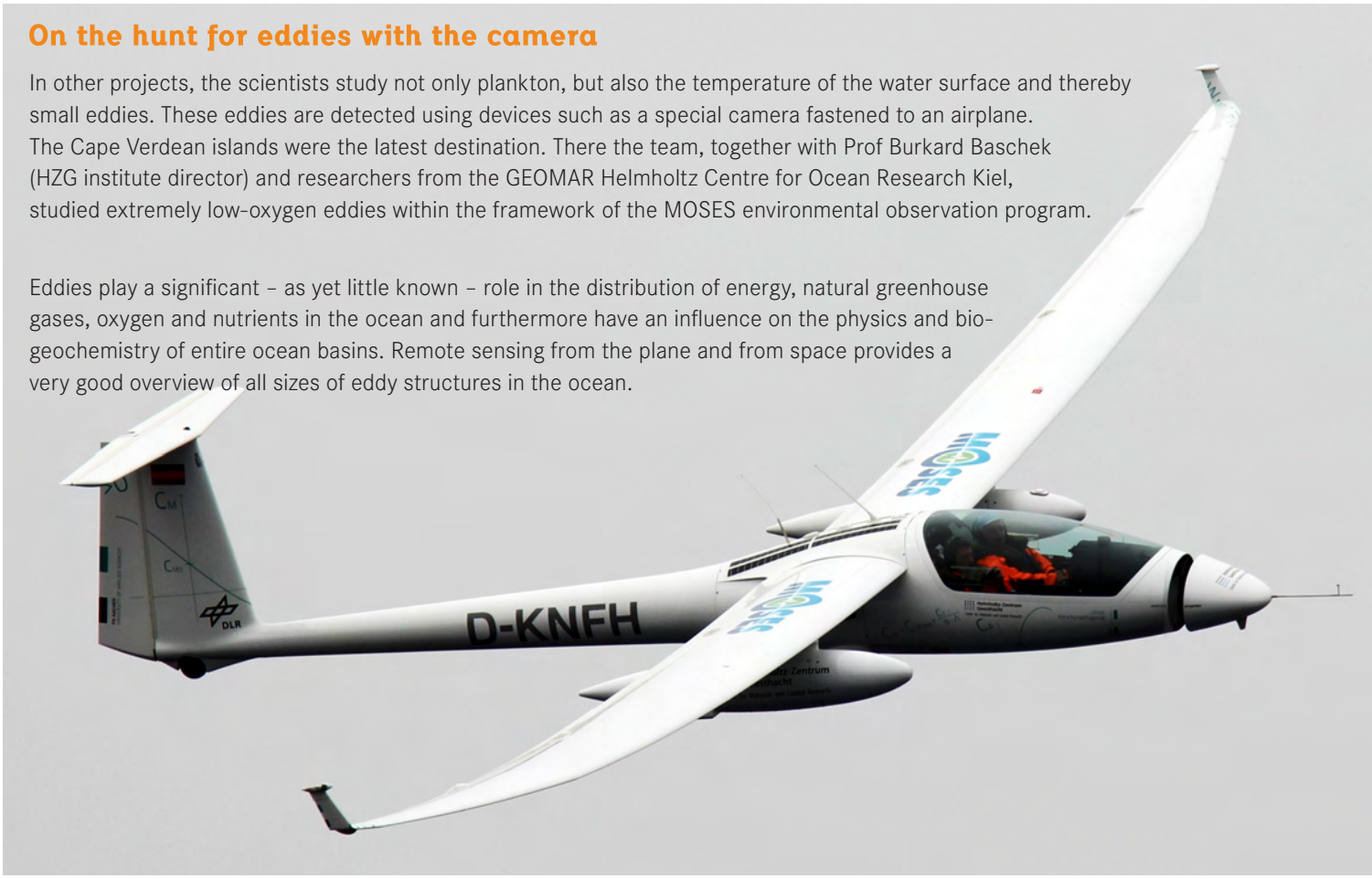
The satellite sensors measure in the visible and near-infrared range, but only in defined parts of the spectrum. Only around ten to twenty per cent of the blue shades that the satellite detects stem from the water itself.

The glittering sun, water vapour or ozone in the atmosphere influence the measurements and must be corrected. The HZG coastal researchers determine these values with their instruments directly on the water and compare them with the satellite data.

On the hunt for eddies with the camera

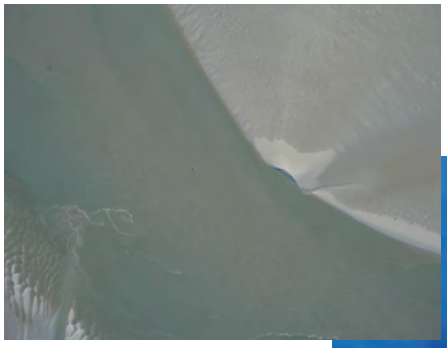
In other projects, the scientists study not only plankton, but also the temperature of the water surface and thereby small eddies. These eddies are detected using devices such as a special camera fastened to an airplane. The Cape Verdean islands were the latest destination. There the team, together with Prof Burkard Baschek (HZG institute director) and researchers from the GEOMAR Helmholtz Centre for Ocean Research Kiel, studied extremely low-oxygen eddies within the framework of the MOSES environmental observation program.

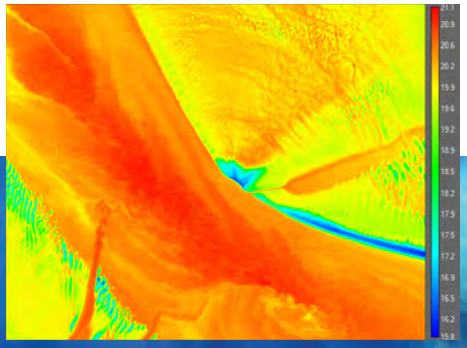
Eddies play a significant – as yet little known – role in the distribution of energy, natural greenhouse gases, oxygen and nutrients in the ocean and furthermore have an influence on the physics and bio-geochemistry of entire ocean basins. Remote sensing from the plane and from space provides a very good overview of all sizes of eddy structures in the ocean.



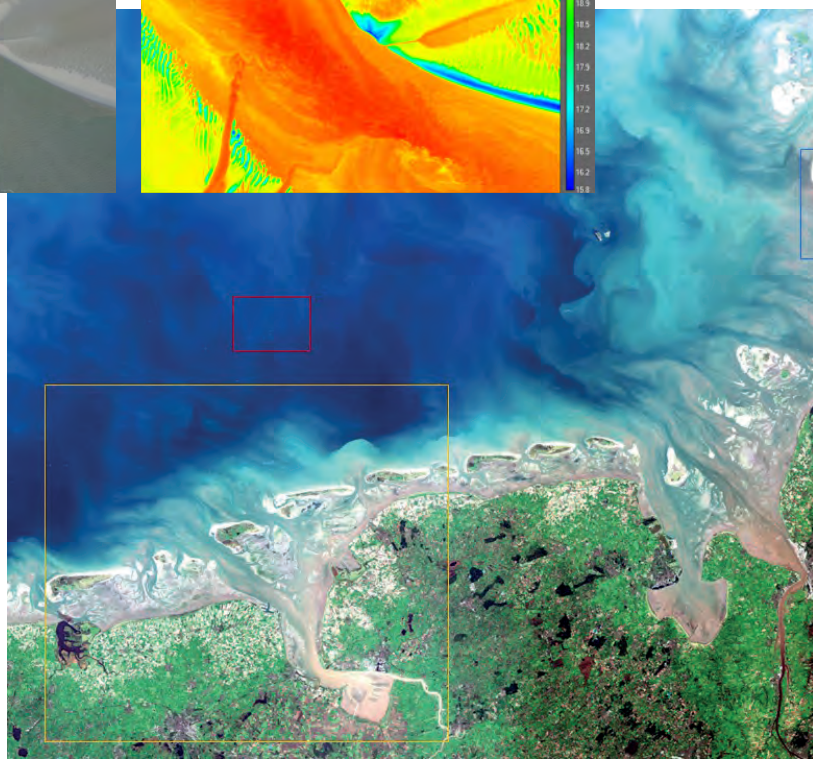
More than just water

Two camera systems are installed on board: a hyperspectral camera and a thermal camera. The researchers obtain a wide range of insights from the resulting images.

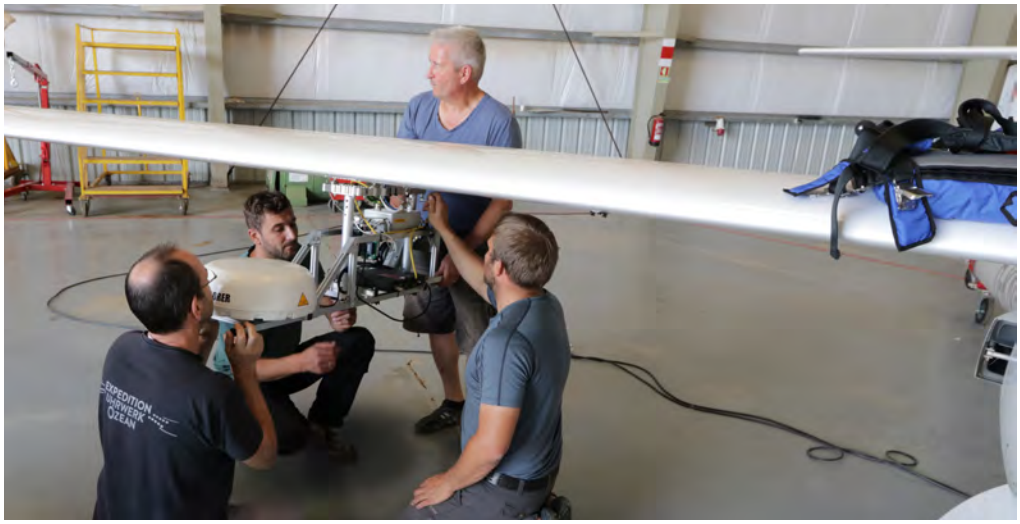




A thermal camera image shows a mudflat here (center right). Surface temperatures can be seen in degrees Celsius. The mudflats are heated by the sun at different rates and cooled by the wind. This enables the researchers to draw conclusions about the water coverage.



The German Bight from the satellite perspective (Sentinel-2/MSI, ESA): this facilitates the study of exchange processes between land, mudflats and sea as well as the effects of offshore wind parks (top image).



©FelixStübing/FH Aachen

Technology on board

Henning Burmester checks the hyperspectral camera. This device records up to 160 different bands of the light spectrum with its special sensors, from visible light to infrared, and is thereby able to determine the colour of the water. This enables the scientists to make statements about the condition and growth of the algae from the air.

The FH Aachen's *Stemme* research plane equipped with remote sensing measurement systems from the Helmholtz-Zentrum Geesthacht on the Cape Verdean island Sal shortly before heading to the measurement area over the open ocean.

Further photo features can be found in our media library:

www.hzg.de/media_library

©ESA/HZG/IFK/KOF

©HZG/Henning Burmester

The Stemme on the Cape Verdean island Fogo.

Two Ambassadors for Hydrogen

Hydrogen is considered one of the key technologies in the energy transition. It can store renewable electricity, can power automobiles, ships and aircraft without releasing emissions and can facilitate CO2-neutral steel production. But how can a hydrogen economy be established everywhere? Two individuals particularly interested in this new technology discuss the matter: the Hamburg Economics Senator Michael Westhagemann pursues the vision of making the Hanseatic port more climate friendly with the help of hydrogen. And the HZG researcher Thomas Klassen develops technologies with which this green energy source can be produced and stored more efficiently than ever before.

There are many successful pilot projects for producing, storing and utilising hydrogen. What is necessary to help this technology make a breakthrough?

Westhagemann: We now need to show that the hydrogen economy can be economical. To do so, we need large facilities on the industrial scale – for example, for CO2-neutral hydrogen production. To implement this concept we want to build an electrolyser in Hamburg Harbour that splits water with the help of regeneratively produced electricity, thereby producing green hydrogen. With a 100 megawatt capacity, this electrolyser will be a considerably larger project than any before – a real flagship of an endeavour. This facility could even be finished in 2023. The first consumers could be a steel mill and an oil company that want to produce synthetic kerosene. Later, the many trucks on the road daily in the harbour area could be powered by hydrogen – including even smaller ships.

Klassen: Technologically we're pretty far advanced in Germany. What is still lacking in part is the interplay of individual components, the interaction of production, storage and consumption in large industrial systems and applications. Here is where policy is really needed, and Michael Westhagemann is one of the protagonists propelling the issue forward. His initiative, to construct a 100 megawatt electrolyser in Hamburg Harbour, is a project that can strikingly demonstrate hydrogen's potential.

About

Michael Westhagemann has been Hamburg's economics senator since 2018. Before taking on this role, the industrial manager with no political party affiliation managed the northern region for Siemens for a long period of time and there his responsibilities included overseeing the wind energy division. Westhagemann is a member of the TU Hamburg's Advisory Board as well as chairman of the board of the Society for the Advancement of the Renewable Energy Hamburg Cluster (EEHH).

About

Prof Thomas Klassen heads the department of Materials Technology within the Institute of Materials Research at the Helmholtz-Zentrum Geesthacht. He is also professor of industrial engineering at Helmut Schmidt University in Hamburg and is member of the board of directors at the Centre for High Performance Materials, a collaboration between the HZG and TU Hamburg.

Photos: ©HZG/Christian Schmid

Hydrogen: between strategy and applied research. Institute Director Thomas Klassen (left) invited the Hamburg Economics Senator Michael Westhagemann (right) to a talk in Geesthacht.

Michael Westhagemann: The German National Hydrogen Strategy and the "Green Deal" of the EU are a natural boost for larger hydrogen projects.

There are certainly other research issues still. What are they and how can the Helmholtz-Zentrum Geesthacht help resolve them?

Klassen: We are working on storage in metal hydrides, which are metals that can absorb hydrogen like a sponge. The amazing aspect is that double the amount of hydrogen fits in a metal hydride tank as in an equally-sized compressed or liquid gas tank for hydrogen. In order to convert our research into practice, we are working with the automotive industry – specifically with Volkswagen – and are on the right track. We are also developing what are known as photo-electrochemical cells. They can split water directly with sunlight and possess the potential to produce hydrogen with a great deal of efficiency. We've already constructed small prototype cells, and I can imagine that we'll have products ready for the market in five to ten years. And finally, our polymer researchers are working on membranes that filter hydrogen from a gas mixture. It's conceivable, for example, to produce hydrogen with excess wind power and to feed it into the Hamburg gas network. If the hydrogen is needed somewhere, it could be separated from the natural gas with these membranes. This means hydrogen could simply be transported in the gas network and a separate hydrogen pipeline network would not be necessary.

Mr Westhagemann, you have co-initiated the Northern German Hydrogen Strategy. And in June, the federal government introduced the National Hydrogen Strategy, a multi-billion Euro program. The EU also wants to support this technology with its "Green Deal". What can we hope for from these initiatives?

Westhagemann: That is naturally a boost that should greatly accelerate development. Funding support is now available for implementing larger projects and also in the most varying of fields – in aviation, for example, which has heavily been shaken by the corona pandemic. Offering climate-friendly flights, particularly for short hauls, will become increasingly important for airlines in the future. Airbus has

already taken up this issue and is developing a hydrogen-powered passenger jet that should be ready for the market in 2030. Another area is in the hauling of heavy goods: a truck or bus powered by batteries makes less sense because batteries are heavy and require a great deal of time to charge. This is something that manufacturers in Asia have long understood and why they are placing their bets on hydrogen and fuel cells. One other example is in shipping: here I find the HZG plan highly interesting, to equip their research vessel to use hydrogen power.

Which collaborative projects between HZG and Hamburg exist already and which ones are in the planning?

Klassen: In a larger consortium, we want to aid Hamburg Harbour in converting to green hydrogen. This includes all logistics as well as ship propulsion. Here we collaborate with various Hamburg companies and universities as well with the new DLR Institute of Maritime Energy Systems, which is currently being created in Geesthacht and will, for example, develop climate-friendly propulsion systems for ships. In another project, we are collaborating with Stromnetz Hamburg and Gasnetz Hamburg as well as with Helmut Schmidt University to link the electricity and gas networks. We are also working together with Airbus and TU Hamburg on a concept to develop the energy infrastructure: it's certainly of no use if an aircraft flies on hydrogen but has nowhere to refuel. Here there are two options. It would be possible that an aircraft – such as that planned by Airbus – could fly directly with hydrogen and all airports would provide hydrogen in the future. Hydrogen, however can also be used to produce synthetic kerosene that can power today's aircraft. Both paths ultimately lead to the goal. It remains to be seen what the more economical and climate-friendly route is for short and long flights.

Westhagemann: Above all, these networks are vitally important to further develop the hydrogen economy and to identify new thematic topics. It is, however, not at all easy to set up and design such networks, as partners must first find each other. This worked very well here and I'm thankful to the Helmholtz-Zentrum Geesthacht that we can together develop these topics in a network.

Michael Westhagemann: We want to build an electrolyser in the Hamburg Harbour that splits water with regeneratively produced electricity, thereby producing green hydrogen. With a 100 megawatt capacity, this electrolyser will be considerably larger than any before - a real flagship of a project.

Photos: ©HZG/Christian Schmid

In the HZG laboratory, Dr Julian Jepsen (center) explains how the raw material for the metal hydride-based storage that is developed at the Helmholtz-Zentrum Geesthacht is produced. The light metals are ground into an increasingly fine powder so that the surface area increases and more hydrogen can be absorbed.

The Helmholtz-Zentrum Geesthacht's fleet includes a hydrogen vehicle. It refuels with hydrogen, which is converted into electricity in a fuel cell. The electricity drives the electric motor, producing only water vapour as exhaust. Institute Director Klassen (left) with politician Westhagemann (right).

Thomas Klassen: Linking the sectors is very important, that is, to integrate electricity, heat and mobility. This way renewable energies could be optimally utilised.

A great deal of green energy is required for a comprehensive hydrogen economy. Where could that come from?

Westhagemann: We likely won't produce it all ourselves, Instead, we need to see where hydrogen can be economically produced with regenerative energy – for example, with solar energy. There are sunny countries, such as Portugal, Spain and Italy as well as the Arab nations. Countries such as Saudi Arabia and the United Arab Emirates prospectively want to leave the crude oil industry behind and they have recognised a new opportunity in becoming green hydrogen exporters.

The hydrogen economy requires its own infrastructure of fuelling stations and storage facilities. How is that to be developed everywhere?

Westhagemann: Germany currently has a network of approximately one hundred fuelling stations. By the end of 2022 it should be two hundred. The question is: how does it look beyond our borders? It would obviously not be advantageous if trucks on their way to Scandinavia couldn't refuel with hydrogen in Denmark. We therefore engaged in dialogue with neighbouring states; we want to create a northern European congress to better synchronise in the future and to provide infrastructure across national borders.

Klassen: We are developing concepts in which fuelling stations are integrated with existing energy infrastructures. These sites can then utilise surplus energy in the network for producing hydrogen for the fuelling station and can also use hydrogen for reconversion to electricity or for heat generation. Within the Northern German Hydrogen Strategy and together with a group of experts, we are establishing suitable criteria for determining locations.

And now a glimpse into the crystal ball: in which sector could hydrogen be established first – in transport, industry or in the energy sector? And where will we be in five to ten years time?

Westhagemann: In terms of the Hamburg Harbour, my hope for 2025 is for larger projects in the petroleum and chemical industries. The first trucks in the harbour should be low-emission vehicles, perhaps even some trains as well. Then we could better determine how much CO2 could be conserved with the new technology and what could be envisioned by 2030. As the first large-scale application, I could imagine trucks and buses running on fuel cells and hydrogen.

Klassen: It is also important to link the sectors – that is, to integrate electricity, heat and mobility. This way renewable energies could be optimally utilised and integrated into our system. One example is that we have so far been wasting 1.5 billion Euros in green electricity every year in Germany due to an oversupply of wind that is not fed into the grid. With this surplus electricity, hydrogen could be produced that could then be utilised in different sectors – be it for reconversion to electricity when the wind isn't blowing or as fuel for vehicles or for heat generation. By linking these sectors, I see enormous potential, economically as well.

Thank you for your time!

The interview was conducted by science journalist Frank Grotelüschen.

Down to the Smallest Detail: New Systems at the Beamline

Making the invisible visible - that's the aim of the scientists working at the HZG's beamline endstations at the Deutsches Elektronen Synchrotron DESY in Hamburg. At the Imaging Beamline (IBL), the HZG teams have installed entirely new and unique detector systems that allow researchers to study their tiny samples even faster and more precisely.

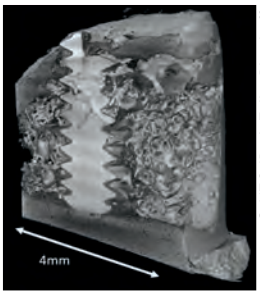
The most brilliant storage ring X-ray source in the world is located at DESY, the Petra III. The storage ring with a circumference of 2304 metres has 24 beamlines. One is the imaging beamline P05, which belongs to HZG and is supervised by its researchers.

The P05 has two measurement stations with fixed research groups: micro-tomography and nano-tomography. In recent years, both groups have carried out their own research and have assisted external user groups with their projects, as no one knows the beamlines as well as the IBL team themselves. This is the reason users come from all over the world to have their samples X-rayed.

Non-destructive X-rays

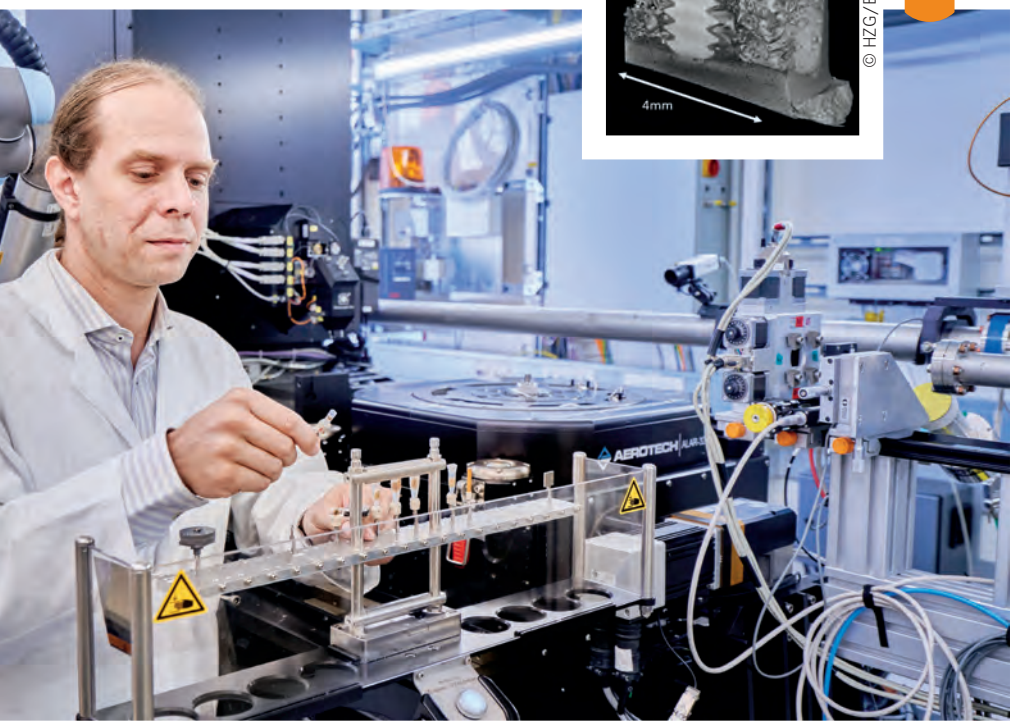
What is special here is that the scientists can take a glimpse inside the different materials without destroying them - whether they are metal or biologic samples. The IBL was created especially for in situ measurements and has been constructed with high flexibility to serve a wide variety of research fields: from materials science to medicine and biology to palaeontology. Only those who know the material structure down to the nanometre scale can begin to understand how they function or from where certain properties stem.

The aim of the researchers is to visualize the largest possible area of any sample, as quickly as possible and in high resolution with the best possible contrast as a three-dimensional image on the computer. From a purely technical point of view, not all criteria could be fulfilled at the same time. With the new detector systems in micro- and nano-tomography, the HZG scientists have taken a huge step closer to the ideal result though. Along with the constant new developments on the market for mobile phone cameras, the detectors that can be used in science have also become increasingly better.



© HZG/Berit Zeller-Plumhoff

#1



Photos: ©HZG/Christian Schmid

Dr Jörg Hammel has been supervising the most widely varying user groups and experiments as beamline scientist at the HZG since 2014.

© HZG/Lucian Blaga

#2 Keeping an eye on the samples: beamline scientist Dr Fabian Wilde has been working in X-ray imaging with synchrotron radiation since 2010.

Micro

Unique: samples with a diameter of one centimetre can be X-rayed and precisely imaged with an accuracy of one micrometre at the micro-tomography station.

What's New?

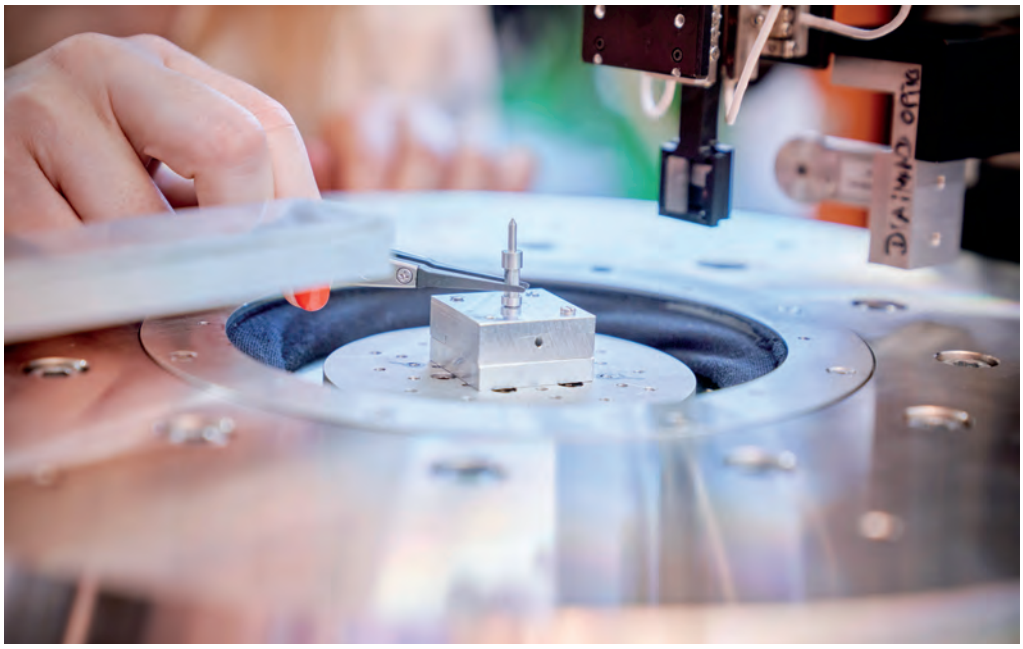
With fifty megapixels, the new detectors at the "micro station" now have five times higher the resolution than the old detectors and are extremely sensitive. The samples can also be measured considerably faster using new contrast methods, whereby larger sample images are created.

#1 **Magnesium Implant**

The bone screw made of magnesium stems from the HZG department of "Metallic Biomaterials." In order to study how precisely the implant degrades in the bone, a sample measuring 5x5 millimetres in size is X-rayed. With the old cameras, only sections of the sample could be viewed, whereby individual images ultimately needed to be pieced together. Now the entire sample can be imaged on the computer as a three-dimensional dataset with an accuracy of a micrometre.

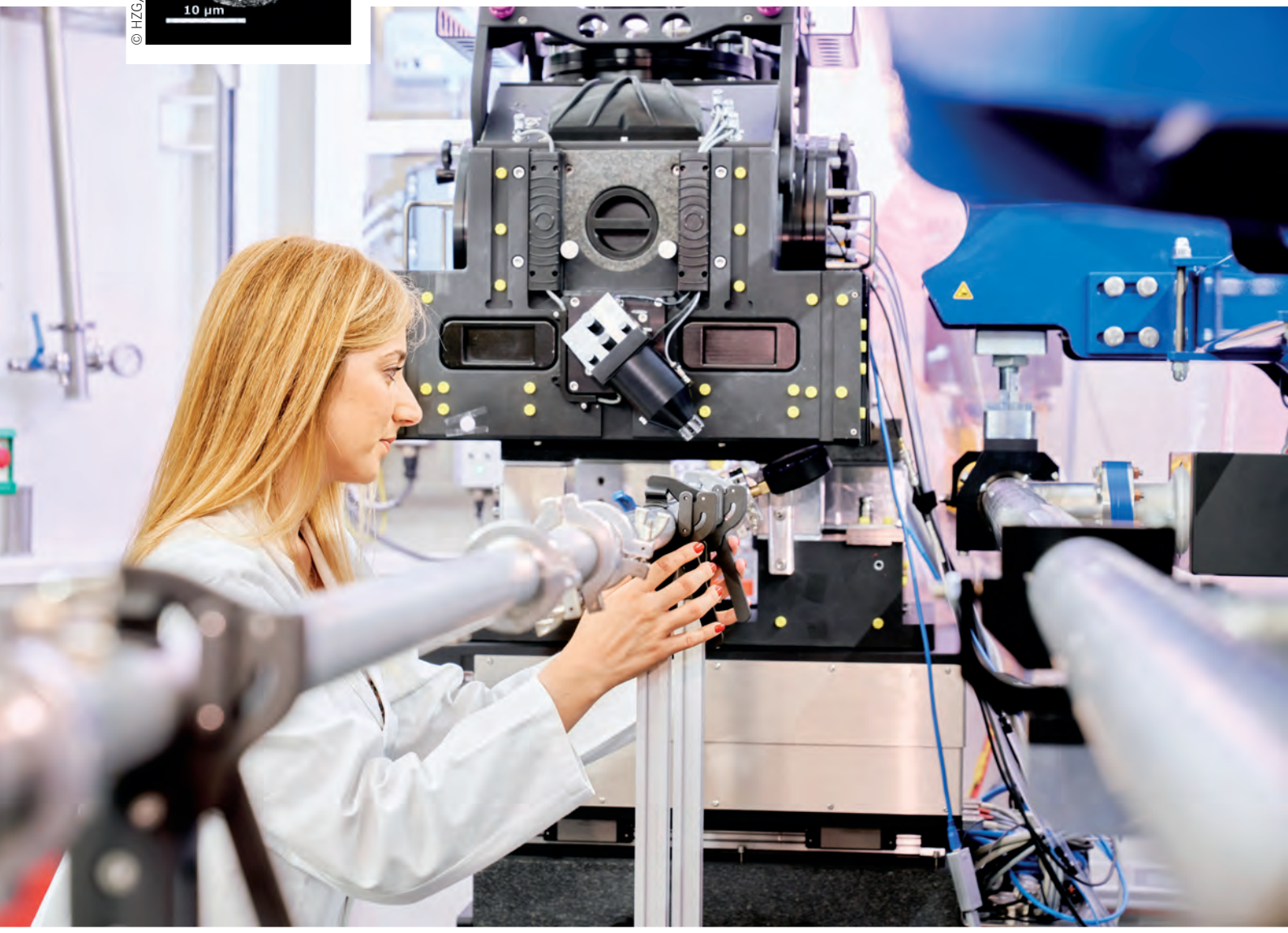
#2 **Joining Methods**

Using innovative joining processes developed at the Institute of Materials Research, the most varying materials can be joined to one another. Metals with plastic. Composite with aluminium. Or titanium with steel. The samples are X-rayed down to the smallest detail. This is how the researchers can ascertain how the materials behave during joining and can better understand the process. A composite can be seen here, created using U-Joining, a method patented by the HZG. In this process a titanium alloy is joined to a fibre-reinforced plastic.



© HZG/Berit Zeller-Plumhoff

Photos: ©HZG/Christian Schmid



Nano

Whenever smaller and even more detailed images are required, thereby exceeding the capabilities of the micro station, nano-tomography is used. The samples studied here are often only as thick as a human hair. With the help of X-ray optics, structures can be imaged that are less than forty nanometres in size - that is less than a thousandth the thickness of a single hair.

What's New?

The HZG's Central Technical Department has constructed the new camera tower at the beamlines exactly according to the researchers' specifications - there's no other like it in the world! With the new camera tower, the new detectors from micro-tomography can also be used for nano-tomography. This considerably increases the flexibility of the nano-tomography. One scan would earlier take eight hours, but the new cameras only need a few minutes. This allows the researchers to measure very quickly compared to other cameras.

#3 Magnesium Implant

In order to study the exact corrosion processes at the interface between the screw and bone, micro-tomography Example #1 is examined again at the nano-tomography station. To do so, tiny pieces of the corrosion layer are extracted and positioned in the X-ray beam.

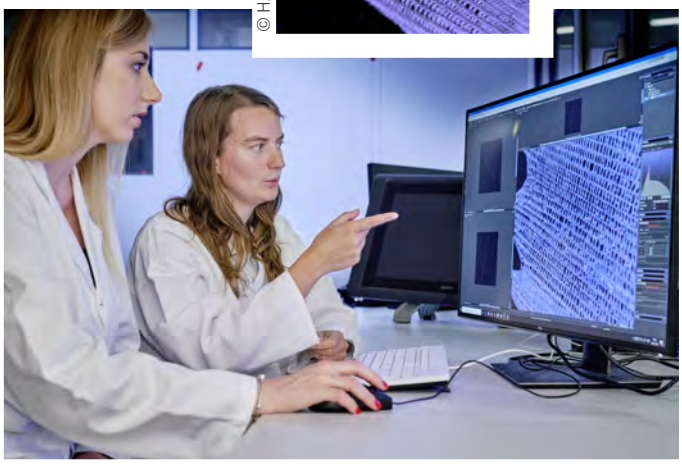
#4 Butterfly Scale

Butterfly wings often gleam in the most fabulous colours - some species, such as the blue morpho butterfly, use a trick for this. They do not have any colour pigments on the scales of their wings. The scales are colourless, arranged like a fir tree. This arrangement absorbs all the colours of sunlight except blue light, which is reflected back. That is why the morpho butterfly looks blue. Scientists at the University of Sheffield have studied precisely how the structure is formed with the help of HZG's nano-tomography station. With this knowledge, non-fading dyes can be produced.

#4

© HZG/Silja Flenner

Dr Elena Longo has been working for two years at the HZG's DESY site in Hamburg. Here she is studying the butterfly scale images with doctoral candidate Silja Flenner.



Author: Gesa Seidel (HZG)

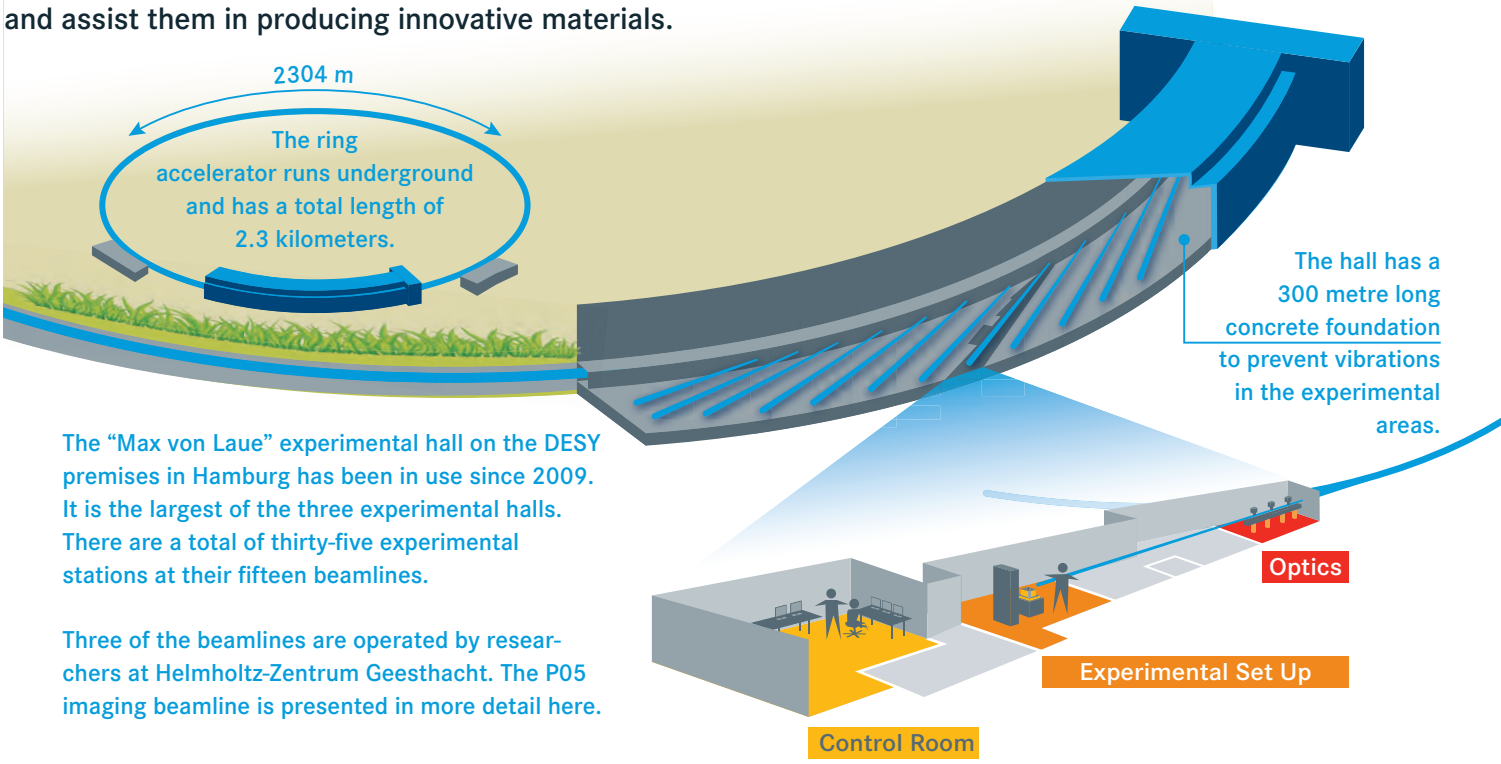
Outlook

PETRA IV

The next generation of storage ring X-ray sources is already in the planning at DESY. The beam will become even more focussed with PETRA IV. Optimised phase contrast procedures will then be possible for the HZG researchers, something from which especially materials scientists can benefit. The new installation is to be built in the existing PETRA III ring tunnel and will begin operation in 2027. "PETRA IV and the ground-breaking nano-focussing ability will provide us with outstanding research opportunities for producing new future-oriented and resource-saving materials," says Prof Matthias Rehahn, scientific director of the HZG.

A Deeper Insight with X-ray Light

A special X-ray light is produced at the HZG's beamlines located at the Deutsches Elektronen Synchrotron DESY in Hamburg. This light from the accelerator is up to one million times brighter than the X-ray tubes in a hospital. The researchers use the light to study various materials such as tissue or welded joints. The experiments help them understand the material properties far better and assist them in producing innovative materials.



The "Max von Laue" experimental hall on the DESY premises in Hamburg has been in use since 2009. It is the largest of the three experimental halls. There are a total of thirty-five experimental stations at their fifteen beamlines.

Three of the beamlines are operated by researchers at Helmholtz-Zentrum Geesthacht. The P05 imaging beamline is presented in more detail here.

Control Room

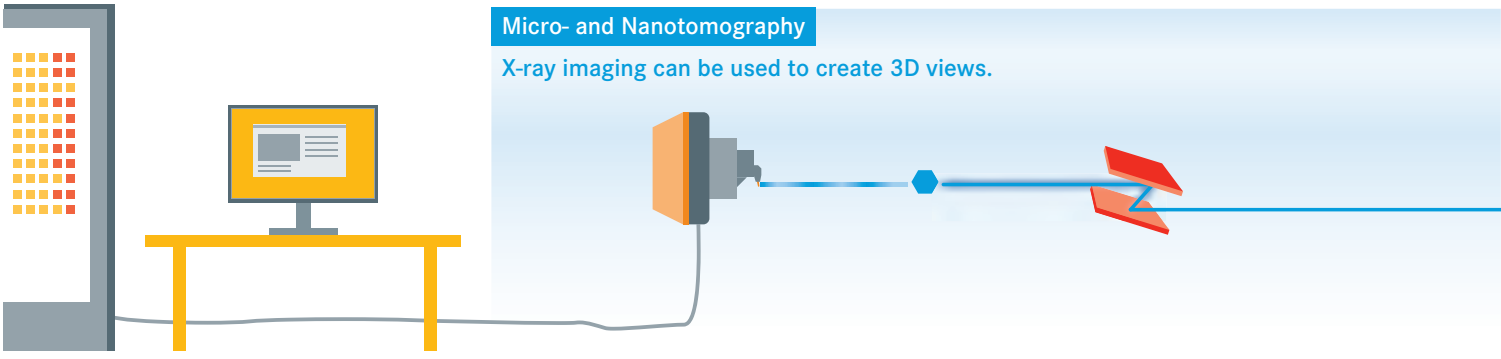
The researchers observe their experiments here and later evaluate the results. Approximately 120 experiments per year are carried out at the facility by the HZG. Numerous other user groups from the scientific and economic sectors can also conduct their tests at the HZG beamlines.

Experimental Set Up

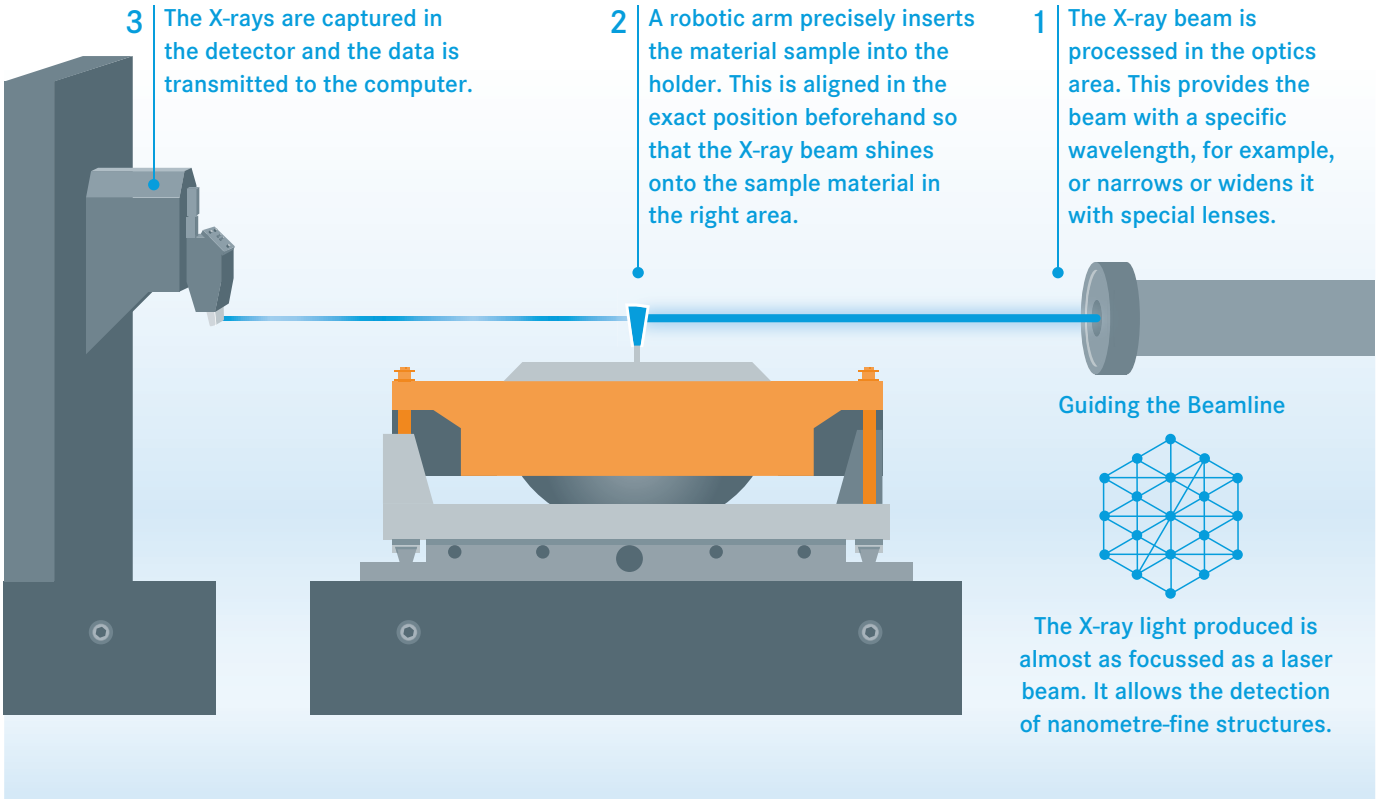
The X-ray light hits the material sample here. Depending on which material is to be X-rayed and how the sample looks, there are various methods for examining the samples: for example, micro -or nanotomography as imaging techniques or X-ray diffraction for the investigation of the atomic structure.

Optics

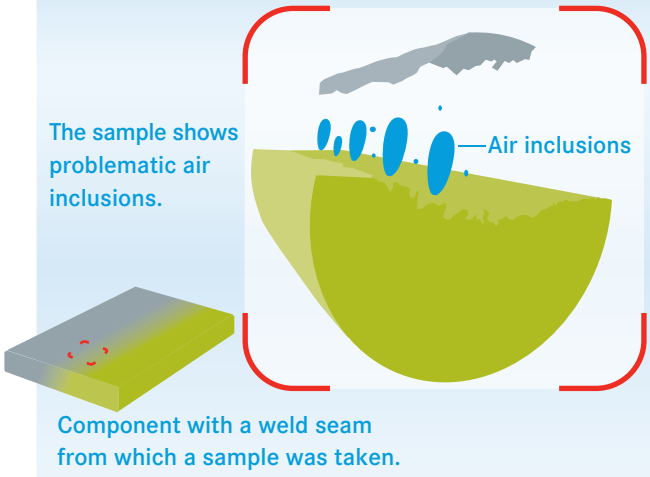
The radiation deflected from the ring accelerator must be prepared optically. For example, this provides the beam with a certain wavelength.



Configuring an Experiment

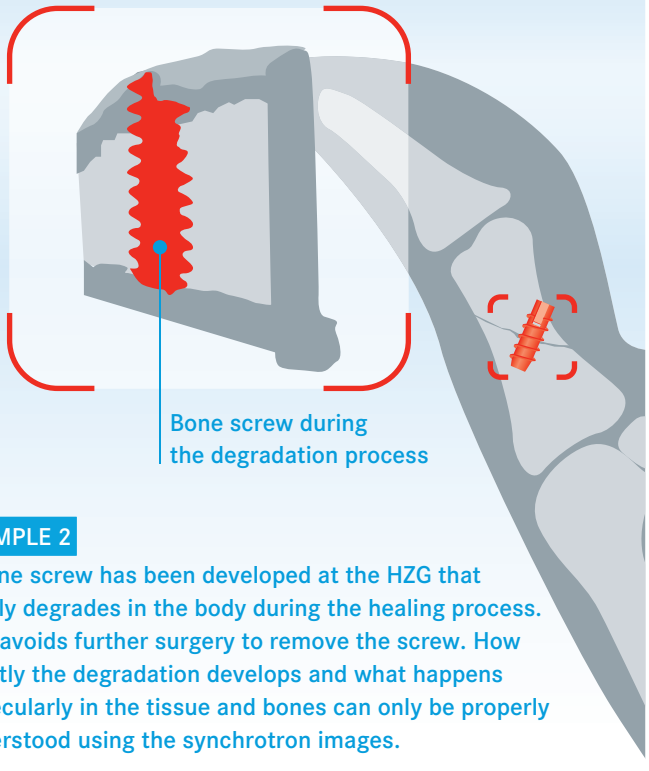


How are the beamlines used for science?



EXAMPLE 1

Friction stir welding produces strong joints - for example, between materials such as carbon fibre-reinforced plastics and metal. Using the X-ray beam at the DESY particle accelerator, the results can be checked down to the molecular level as to whether the joint succeeded and how the joint seam looks inside.



EXAMPLE 2

A bone screw has been developed at the HZG that slowly degrades in the body during the healing process. This avoids further surgery to remove the screw. How exactly the degradation develops and what happens molecularly in the tissue and bones can only be properly understood using the synchrotron images.

The Secret Agent among Researchers

What drives Institute Director Burkard Baschek?

Find more portraits online:

www.hzg.de/portraits_en

Prof Burkard Baschek

leads the Operational Systems division at the Institute of Coastal Research

Science has long failed to study small water eddies. They move across the surface for too short a time. Oceanographer Burkard Baschek, however, made the breakthrough - since then, the eddies have never let him go. Today he studies the phenomenon using a mix of a high tech and hands-on approach.

Physics? "I dropped the subject as early as possible," says Burkard Baschek, world renowned oceanographic researcher - and physicist. The 49-year-old smiles. He knows how surprising this aversion sounds today. After all, he's been long regarded as one of the leading physical oceanographers. It's the ocean's dynamics he is taken by above all else: Baschek researches the small eddies at the ocean's surface. They appear unexpectedly, moving the seawater layers with tremendous force - and then dissolve after merely a few hours. Few other researchers in the world have studied this phenomenon as extensively as Baschek, a director at the HZG's Institute of Coastal Research.

As a child, however, it was the biology of the sea that fascinated him more. "It was during my civil service on the Sylt mudflats that I realised I was not only interested in nature conservation," reminisces Baschek today.

> **I wanted to understand the marine system much more comprehensively.**

That's why he enrolled in physics, first in his hometown of Heidelberg, then transferring to Kiel after two years, where he studied physical oceanography.

He was then drawn to far away places, to Canada and the United States. There he stayed for thirteen years, researching and teaching. At the time, marine science was only just beginning to understand that an unexplained driving force in the oceans existed: computational models show that the small eddies form everywhere within the oceans across the globe. It has, however, never been possible to document their occurrence or carry out systematic measurements - the approach as to how to obtain this data was missing. This is because the small eddies disintegrate much faster than the large ocean currents, such as the Gulf Stream. "Measurements can therefore hardly be planned," explains Baschek, "but we researchers must spontaneously react as soon as we spot an eddy from the air, then carry out as many measurements as possible."

His first solution to this problem is a special rope onto which several sensors can be fastened at the same time - he pulls this measurement line at unusually high speed through the seawater.

Baschek also launches aircraft into the sky that are equipped with special thermal imaging cameras. They can register temperature differences of only 0.03 degrees. They open up a view of how the water layers of different temperatures mix in an eddy. This measurement system is unique even today - and is ahead of the pack globally. In fact, the researcher succeeds in recording data from inside an eddy for the first time.

It is sophisticated developments like these that have earned Baschek the reputation as the "James Bond of science." He enjoys tinkering around, testing the most modern technology (currently, artificial penguins and augmented reality glasses), but he also likes to combine simple, well-known devices together.

Technology, however, shouldn't be an end in itself, Baschek points out, but must always remain in relation to the goal of a research project. For his most famous expedition to date, Clockwork Ocean, for example, he not only launched speedboats, aircraft and underwater robots in 2016, but also launched a Zeppelin, which floated over Germany and travelled to its operational region above the Baltic Sea. While this drew enormous attention to the project, it was primarily to serve research, as the Zeppelins can be "parked" in the air like no other aircraft. This allows an optimal and constant view of the eddies. This measurement system is unique even today - and is a global leader.

Expeditions like these are the "highlights of a researcher's lifetime," says Baschek. Last year, for example, he travelled with colleagues to Cape Verde. In the waters off the archipelago he studied nutrient transport by ocean eddies. It is unclear whether they also transport nutrients from the lower layers of the sea to the upper, light-flooded areas and thus stimulate algal growth. "We currently assume that approximately half of the global phytoplankton is produced in small ocean eddies," says Baschek. The eddies could therefore be vital for life in the sea.

Teamwork is particularly important for the institute director on these expeditions: "We all make strides when different disciplines together look at a region or a research question." Baschek is also a team player in his private life: he plays canoe polo and enjoys diving with friends - in areas such as the Great Barrier Reef. The corals off the coast of Australia are fascinating to the researcher: "Their biodiversity shows us very clearly what we're losing if don't protect the sea." The oceanographer explains that locations like Hamburg's Tropical Aquarium, which show living corals and support the protection of wild reefs, are therefore an important component for species protection.

> **We all make strides when different disciplines together look at a region or a research question.**

But as important as the exchange with friends and colleagues is to him, sometimes Baschek likes to withdraw entirely. Early paddling trips took him to Alaska, where he spent five weeks alone in the wilderness. "I've also paddled through the eddies that I'm researching," says Baschek. "But in these moments, I see only nature: the glow of the sea and the calving glaciers, orcas appearing next to my kayak or bears hunting on the shore." There it is again: the thrill of marine biology. In the shape of a physicist.

Author: Jenny Niederstadt

Leaving the Established Path

At the Institute of Biomaterial Science in Teltow, medical possibilities are revolutionized, artificial muscles for soft robots are created and cognition processes are dramatically accelerated.

"In the future, we'll be increasingly confronted with age-related illnesses," says Andreas Lendlein, director of HZG's Institute of Biomaterial Science in Teltow. "That is why we're concentrating on innovations in the fields of health, medical and bio technologies." One of the topics the researchers are working on includes applications that support elderly people in their domestic environments before they even become sick. If tissues or organs are damaged or diseased, it is important to support the body in fully regenerating. New polymer-based biomaterials are required for this purpose. They are synthetic or semi-synthetic materials consisting of macromolecules.

"Our work spans from basic research to application," explains the institute director. "We are searching for new ways to treat diseases that are particularly relevant for the healthcare system, improving therapies and developing alternative approaches." In order to efficiently bring pre-clinical research into clinical development, an interdisciplinary approach is used right from the start. Biology, chemistry, materials research and medicine come together here. From research activities to the decision making, the institute collaborates closely with partners from the medical field, both in Germany and abroad.

"We are, for example, developing materials for implants that integrate fully into the tissue or that can even provide functional support," says Lendlein. "Effects from inflammation are minimised, while regeneration processes are stimulated and ideally guided in the desired direction." Depending on what the biomaterial implant is made of, it degrades completely within a desired period of time and until then supports the complete recovery of the surrounding tissue.

The researchers at the HZG institute use algorithms to also make leaps in the long-term behaviour predictability of polymers so that the research cycles are dramatically accelerated and their results can be applied in practice more rapidly.

Author: Lars Klaaßen

The HZG's Institute of Biomaterial Science is located on the Teltow-Seehof research campus. The new SEE:LAB Biomaterials Competence Centre is also under construction there. SEE:LAB is meant to enable innovative companies to settle in the immediate vicinity of the research institutions.

Prof Andreas Lendlein has been leading the Institute of Biomaterial Science since 2002.

Videos and 360° clips about the location:

campus-teltow.hzg.de/standort

Muscles for Soft Robots

Novel plastics react to signals such as temperature or magnetic field and move accordingly. Such materials are reprogrammable in that they can be trained in different motion sequences.

We live in a society that is increasingly shaped by the need for services, a world in which more and more elderly people rely on assistance in their everyday activities and on the field of medicine. In such a society, artificial assistants - what are known as "soft robots" - will become increasingly important. Soft and sensitive materials enable these assistants to better adapt to the environment and work safely with people. "Role models" include creeping plants that feel and react to their surroundings, as well as South American cacti that can move.

"To make materials suitable for certain applications, we program them," says Marc Behl, head of the Active Polymers group. "We lend them this ability through the interaction of processes on molecular and morphological levels." We are familiar with the effect that a material changes its shape under certain circumstances from observing heat-sensitive shrink films or tubes. If these items are heated with a hairdryer - a suitcase, for example, can be densely packed. One shortcoming, however, is that this shrinkage cannot yet be reversed.

"A few years ago, we made considerable progress by creating soft actuators with a shape memory, which then move back again," stresses Andreas Lendlein, head of the research team. "The plastic strands or threads that twist or bend are controlled as needed by different signals such as temperature or magnetic fields." Furthermore, such movements can be performed in a fully controlled manner through individual steps, with pauses of desired lengths where the material remains still. In the future, such actuator materials could be used to build harvesters that swing from tree to tree or care assistants that place people into another bed. To develop artificial robot muscles, the scientists from Teltow now cooperate with experts in soft robotics.

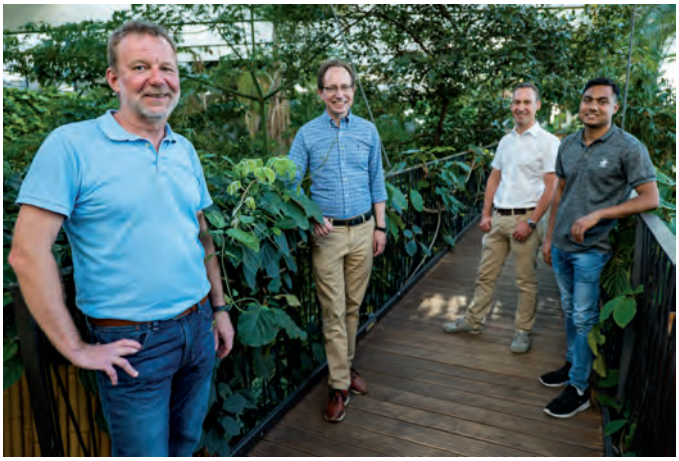
These tendril plants grow and search until they find something onto which they can grab. This allows them to move and cover distances.

Videos and 360° clips about this topic:

campus-teltow.hzg.de/kaktus

©HZG/Gesine Born

Scientist Anil Bastola studies a sample from a special South American cactus. Artificial muscles for soft robots are produced using this plant as a model.



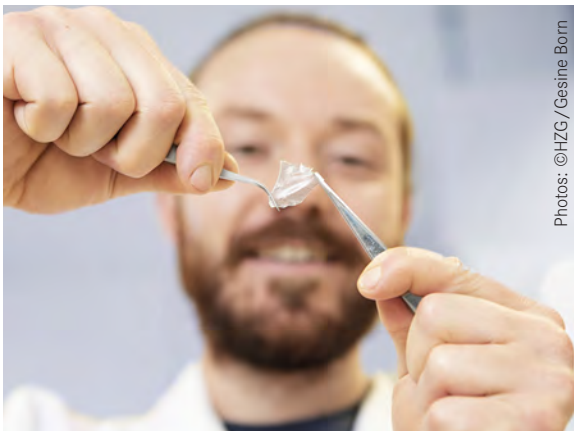
©HZG/Steffen Niemann

From left to right: Nicholas Rowe (CNRS), Andreas Lendlein, Marc Behl and Anil Bastola (all three from HZG) collaborate on the EU soft robot project GrowBot.

Predicting the Lifespan of Plastics

A sustainable use of resources can be achieved through a balanced product life cycle. To achieve this goal, it is crucial to know the product lifespan and long-term behaviour. This would spare the environment and advance medicine. Ultra-thin films and simulations are of assistance here.

Plastic waste in the form of microplastics, for example, pollutes the environment, mainly the oceans. Some materials are considerably more lasting than originally thought - and more long-lived than would be necessary. Others disintegrate more quickly than expected, something that can be equally as problematic. Knowing when certain plastics would entirely biodegrade and under what conditions would have many benefits. For example: with a suture material that simply dissolves at the desired time after a medical procedure. Temperature, pH value, enzymes, mechanical stress as well as the interaction with cells and tissue have an immense effect on the duration of such processes. "In order to accelerate development of new materials that possess the desired properties and functions, we are working on a prediction method for their long-term behaviours," says Natalia Tarazona, scientist at the HZG's Institute of Biomaterial Science in Teltow. "Our aim is to be able to make quantitative statements in a few hours about polymer degradation behaviour, depending on environmental parameters as well as on chemical composition and structure."



Photos: ©HZG/Gesine Born

Dr Natalia Tarazona researches the long-term behaviour of bioplastics. The degradation behaviour of ultra-thin layers provides crucial insights in this regard within a short period of time. The scientists combine this experimentally obtained data with computer models to provide predictions of macroscopic structure. One of these researchers is Dr Rainhard Machatschek.

To do so, a few micrograms of the material are spread out on nanoscopically thin films that are floating on a water surface. The degradation of the chain-like molecules produces water soluble fragments, which reduce the area of the film. The latter can be measured precisely. The scientists combine this experimentally obtained data with computer models to provide predictions of macroscopic structure. For the full description of the degradation behaviour of medical implants or everyday objects, another component is missing. The transport of small molecule fragments from the material as well as the diffusion of water, which is a prerequisite for the molecular degradation processes, cannot be measured in this experiment. "Multi-scale computer simulations, into which we integrate the results from the ultra-thin films, are suitable for this," says Tarazona. "In the medium term, we want to know how the long-term behaviour of a material looks in different scenarios even before the production of test specimens."

"A class of substances that are very interesting to us right now are polyhydroxyalkanoates," adds Tarazona. "These PHAs have the advantage over other plastics of biological origin in that they are completely synthesized in bacteria, which can, for example, be fed with agricultural waste." PHAs were initially brittle and quickly formed cracks. Newer representatives, such as polyhydroxyoctanoate (PHO), are considerably more elastic and flexible. "As very little is known about this PHO's long-term behaviour, we looked at the material under different environmental influences," says Tarazona. "It is completely degradable."

Author: Lars Klaaßen

Videos and 360° clips about this topic:

campus-teltow.hzg.de/flasche

Right to the Heart: Digital Images and 3D Printing

Minimally invasive heart valve procedures can be practiced on models that precisely match the organ's individual anatomy.

Illnesses afflicting the musculoskeletal and cardiovascular systems are the focus of clinical research at the Institute of Biomaterial Science. With a leaky heart valve, for example, open heart surgery was required up until a few years ago to replace the valve with an implant. For the elderly or for people with pre-existing conditions, this procedure was extremely challenging. It is now also possible to restore the natural valve using minimally invasive methods—theoretically.

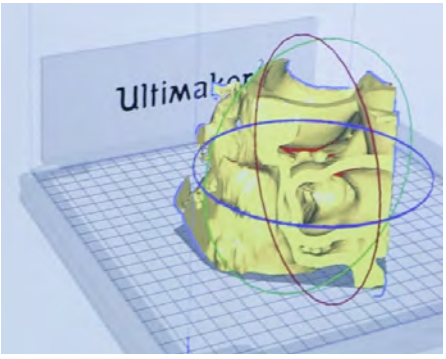
In this type of treatment, a clip is inserted into the right atrium using a catheter. During the procedure, the edges of the leaky valve are connected by the clip at certain points. This at least reduces the leakage. As this is not a surgical procedure under visual control, good imaging is essential. Physicians have so far been using an ultrasound probe in order to view the area. The quality, however, is too often insufficient. "With the help of digital visualisation methods, a 3D printer and an ultrasound probe inserted directly into the heart cavity, we can remedy this problem," says Markus Reinthaler. The director of "Structural Heart Disease" at the Charité's Benjamin Franklin campus also works at the HZG's Institute of Biomaterial Science, cooperating with other researchers towards finding this solution. The additional imaging option includes a small ultrasound probe (ICE catheter) inserted very close to the heart valve, improving the valve's imaging. As cardiac structures differ greatly from patient to patient, methodical training is required to gain familiarity with each heart. Furthermore, two catheters are then in use: the probe and the implant-bearing catheter system.

"Our approach is an individual 3D heart model made of polymer, with which we can find and train the most suitable manoeuvre sequence for the probe with the corresponding positions and orientations," says Reinthaler. For this purpose, three-dimensional heart models were created from the patients' CT data sets and a physical object was created using a 3D printer.

One study comparing patients treated with the previous and new procedure showed encouraging results: the use of the ICE probe with the 3D model training, made it possible to treat patients who could not have been treated using conventional imaging or could only have been treated to a limited extent.

Author: Lars Klaaßen

Videos and 360° clips about this topic:
campus-teltow.hzg.de/herz



Dr Markus Reinthaler develops minimally invasive heart surgery treatments. Training is carried out using individual 3D polymer models.

Mark Schröder in the 3D printing laboratory in Teltow. Using models made of specially manufactured material, researchers can precisely recreate the actual anatomy of any person.

Photos: ©HZG/Gesine Born

The Trainer of Stem Cells

Find more portraits online:

www.hzg.de/portraits_en

Prof Dr Nan Ma

Leader of the "Polymers in Regeneration" department at the Institute of Biomaterial Science

Materials science is a terrific area of research - we not only have the opportunity to conduct basic research and make discoveries, but we can also provide solutions. Solutions addressing the greatest medical challenges. It's an insanely good feeling!

Nan works at the Institute of Biomaterial Science in Teltow. The fact that she wound up in Germany after completing her medical studies and earning her PhD in Singapore can be attributed to her inner drive toward achieving more and her courage to enter new territory. The 48-year-old wanted to be a journalist as a child, but after she finished school, it was clear to her as the daughter of two academics: she was to study medicine. After her studies in Changchun, she quickly noticed, however, that she had repeatedly reached the limits as a practicing physician specialising in oral and maxillofacial surgery. Not her own limits, but the limits of technology. "I had seen a lot of patients suffer from issues such as oral cancer. We could only utilise practices that we had learned. This often meant cutting out the affected tissue," she remembers. "Between discussions with senior physicians, patients and nurses, the only quiet time could be found in the operating room. "That wasn't enough for me. My head was always full. I had no space to think and no space for science."

Nan later headed to Beijing to complete a master's degree in immunology. She then decided on Singapore to study for her doctorate, enticed by the field of gene therapy. It came in handy that her husband held a position in materials science there. Shortly before the birth of her daughter, she and her working group published a paper that managed to make it onto the cover of *Molecular Therapy*. Now she could do what was always important to her: leave behind the limitations of what had already been studied and try out new things.

Singapore provided her with numerous opportunities: research funding, equipment, resources. Ma was not only the first female PhD student at the institute and one of only a few women, she was also responsible for completely building and equipping a new laboratory from scratch. She, however, wanted to get acquainted with Europe.

With only one suitcase, she arrived in Germany as a post-doc to work in the field of heart surgery at the University of Rostock. "I didn't have any winter clothing with me. I only wanted to stay for six months, after all. I encountered tremendous culture shock initially. There wasn't even a single authentic Chinese restaurant in Rostock! My husband supported me a great deal in my career, so my family moved to Germany a short time later." This courage paid off: within a Collaborative Research Centre, she met Andreas Lendlein, director of the HZG's Institute of Biomaterials Science in Teltow. "He believed in me and suggested that I apply for a position as a junior research group head at the Helmholtz Association in Rostock. I didn't expect to, but I got the job."

Five years later, in 2011, she came to Teltow as department head, where she set up a laboratory and formed a group with the help of Lendlein. She was appointed joint professor of biomaterial characterization at the Freie Universität Berlin in 2013. The most important pieces of equipment for the molecular biologist even back then were the confocal microscopes. "I can only believe something when I see it." What she observes with her more than ten microscopes is fascinating. She watches stem cells as they grow and tries to influence their development through physical factors. She is especially proud of one publication: at the start of 2020 she could demonstrate that stem cells could be trained to develop into bone cells using a special polymer film. The film works like an artificial muscle with a shape memory that reacts to temperature changes.

At the moment, Nan and her team's work still lies in the field of basic research. They dream that their research will help solve the most varying medical problems in the future.

Stem cells are like the tiniest computers for me. When we learn how to specifically program them, we'll take a great step forward.

The cells could, for example, learn how to develop into skin cells that can be applied after extensive burns. They could heal bones after fractures. Cardiac cells could be replaced after transplants and heal heart diseases.

"I'm a very shy person. I like working in the laboratory the most, when I can fully focus on the science. I see it as a privilege to be able to work this way."

Ma has been a researcher for many years—she also trains her stamina in sports. Her favourite activity is spinning at the fitness studio. She lives with her husband and two children in Berlin. "The cultural differences are far less noticeable here than in Rostock. Berlin is multicultural—and there's a large selection of outstanding Chinese restaurants," Ma says, smiling.

Author: Gesa Seidel (HZG)

News from the Centre

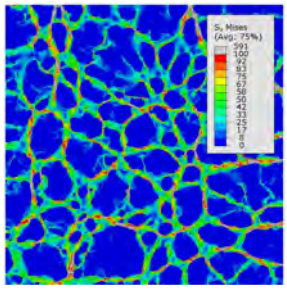
New Concept in Materials: Silicon with Muscle

A smart phone speaker needs what are known as actuator materials in order to function. These actuators perform small movements in the micrometre and nanometre ranges electrically and very precisely, thus causing air, for example, to vibrate. Silicon has never before been capable of performing such functions.

The team equipped the smallest nano-channels in the silicon with the artificial, environmentally friendly and soft polymer polypyrrole. It was therefore possible to make these muscle molecules and thus the entire silicon framework of the hybrid material expand under electrical voltage and then retract again.

To correctly display the material structure, images generated by transmission microscopy (TEM) first needed to be transferred to a calibrated computer model. This step was successfully carried out at the HZG's Institute of Materials Research. Materials researcher Prof Norbert Huber, co-author of the study explains: "The TEM image is only in different greyscale values. It was initially difficult to differentiate the polypyrrole from the silicon. In the end, we could transform the TEM image into a realistic finite element model, therefore learning quite a lot about the actual properties of the very irregularly shaped silicon walls as well as their role in the actuator mechanism."

The study was carried out in CIMMS and the SFB 986 Collaborative Research Centre. The results were published in the journal *Science Advances*.



Stress simulation in the silicon walls, measuring approximately 10 nanometres thick (green-red) due to ion loading of polypyrrole (blue areas).

Publication:

doi.org/10.1126/sciadv.aba1483

Congratulations to the researchers of the Digital Earth project!

In September the team was bestowed the special prize for "Digital Science" at the "Digital Leader Awards". The prizes are conferred across sectors to projects and teams that advance the digital transformation.

In the interdisciplinary Digital Earth project, researchers combine scientific topics such as floods and their effects or methane sources in the German Bight with methods from data science. Dr Diana Rechid from GERICS explains: "We want to obtain a comprehensive picture of events such as an Elbe flood with its causes and impacts as well as how such events will develop in the future under changing climatic conditions." Dr Viktoria Wichert adds: "In order to do so, we combine countless amounts of data from different fields and use, for example, new data science methods such as machine learning."

"What makes Digital Earth special are the multitude of varying disciplines that must come together to jointly develop outcomes such as the "Flood Explorer" or other standardized approaches. We've all learned a great deal and had fun," says coastal researcher Dr Holger Brix.

Eight Helmholtz centres are participants in Digital Earth. HZG scientists from the Climate Service Center Germany (GERICS) as well as from the Institute of Coastal Research are contributing: Holger Brix, Viktoria Wichert, Diana Rechid, Laurens Bouwer, Christine Nam, Bente Tiedje, Lennart Marien, Volker Matthias, Ulrich Callies, Andrey Vlasenko, Nicola Abraham and Jan Arndt.

More information:

www.digitalearth-hgf.de

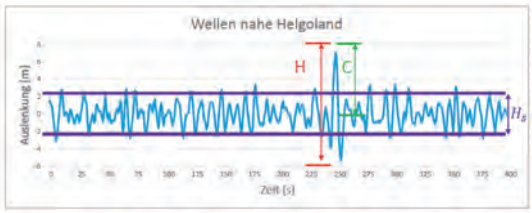
Conspicuously Inconspicuous – Rogue Waves in the Southern North Sea

One million –that's how many measurement series Ina Teutsch and her colleagues have evaluated to determine where, when and how often rogue waves occur in the southern North Sea. The data come from eleven measurement buoys and radars that have been set up or moored at different stations at sea.

"One series of measurements shows data for a thirty-minute period. We therefore know how high the individual waves were for this time interval. We look at the average height of the highest one third of the waves within that half hour. Waves that are more than double the height of this significant wave height are designated rogue waves," explains Teutsch. According to the scientists, most statistical extreme waves are one to two metres high - less extreme than non-experts might expect - and occur several times a day.

The results of the current study show that the distribution of these waves is relatively constant over the course of the year and that the seasons seem to assert no influence. There are also no conspicuous areas in which rogue waves occur more often than in others. However: "We didn't expect the waves to occur so frequently," says the doctoral student, who has been working in coastal research at the HZG for three years. The study was conducted jointly with the German Maritime and Hydrographic Agency and published in the scientific journal *Natural Hazards and Earth System Sciences*.

The researchers now know how often the rogue waves occur, but the reasons for their occurrence still remain ultimately unexplained. Teutsch says, "We suspect that the weather conditions, currents and tides have an influence on the formation of these rogue waves. How exactly they work in interaction is something we need to study further." In the future, the work conducted by the rogue wave researchers should help facilitate forecasts and planning for shipping and offshore facilities.



H- Wellenhöhe C- Amplitude H_s- signifikante Wellenhöhe (der 33% höchsten Wellen)

Rogue Waves are waves that are more than double the height of the significant wave height H_s.

Publication:

https://doi.org/10.5194/nhess-20-2665-2020

A Fresh Wind for Hydrogen

Hydrogen is the most common element in our universe. When energy from this special gas is utilised, it does not leave behind any environmentally harmful CO_2 or methane, but simply water. Climate friendly and space-saving, hydrogen is regarded as a central component of the energy transition. Researchers are developing methods for the safe production, storage, transport and utilisation of this valuable gas.

Regenerative energy is required to produce hydrogen in an environmentally friendly manner. The portion of renewable energies should hit eighty per cent in Germany by 2050. This is why, for example, offshore wind power plants are undergoing massive expansion. Wind, however, doesn't always blow to the same extent. If wind blows excessively, hydrogen can be produced with the surplus electricity from the wind power plants, using what is known as a electrolysers.

This hydrogen can be stored or transported to consumers in the gas network. Materials researchers at the HZG are developing specific storage solutions in which the gas can be firmly bound to metals. The advantages over standard pressure gas tanks include that a much lower pressure is used, making the entire chain more energy efficient, and the volume of the tanks is significantly reduced. To understand the processes within these novel tanks and to further optimise them, the HZG scientists use their measurement stations at DESY in Hamburg (see pages 18-23) and the research neutron source FRM II in Munich.

Whether transported via gas line or stored in a solid fuel tank, the energy inherent in hydrogen is almost always used for industrial processes as well as in the transportation sector after reconversion into electrical energy. This is achieved in fuel cells without releasing pollutants. Ships will soon be equipped with these climate friendly propulsion systems - including the planned LUDWIG PRANDTL II (see page 37). Autonomous underwater gliders are also to receive mini fuel cells and will serve Geesthacht coastal research in the future.

More Information:

hzg.de/frischer-wind-fuer-wasserstoff

Research Vessel LUDWIG PRANDTL Forty Years at Sea

It sways back and forth on the gentle waves of the Elbe in its home port of Oortkaten, waiting for the next exciting adventure: it is the HZG's LUDWIG PRANDTL research vessel.

The vessel is named after the physicist Ludwig Prandtl, who in 1904 succeeded for the first time in visualising flow processes with a water channel. The ship launched in 1983 in Hamburg. Today scientists use the LUDWIG PRANDTL for collecting assorted samples from the water or the seabed and examine them, studying various aspects. Due to its shallow draught (only 1.7m!), it is especially used in areas of shallow water - an important factor for research conducted in rivers and at the coasts. For taking samples, the Ferrybox is often utilised. This is a measurement device that continuously collects data pertaining to the water, including, temperature, salinity, chlorophyll content, turbidity and oxygen content. The researchers use the laboratories on deck the LUDWIG PRANDTL as well as additional measurement devices to do so.

Our research vessel will soon turn forty years old. It's now time to revisit the ship's loveliest moments.

Experiments and Measurement Campaigns

A Wealth of Data

Every year, numerous journeys are taken to collect data and gain new insights. The PRANDTL has been used for many years to study the Elbe, the Baltic Sea and the North Sea. An important research area is the nutrient transport and budgets in the Elbe and its estuary. The first studies on nutrient budgets using the most modern isotope technology began in 2005 and are still carried out today. New studies indicate that the nutrient input is increasing again - mainly due to more intensive agricultural use and fertilisation. The concentrations of compounds such as ammonia and toxic nitrite in the port area are also increasing as a result. This means additional stress for the fish and other living creatures. The scientists have access to a wealth of data for the Elbe, including nutrients, pH values, salinity, temperature and stable nitrogen isotopes that allow the researchers to study and determine the biochemical turnover processes in detail. The studies serve as the basis for many publications. The research ship is also made available to external research groups.

Oderhaff Measurement Pole

The LUDWIG PRANDTL also helps in deploying permanently installed measurement devices: a measurement pole in the Oderhaff (Baltic Sea) was anchored in 2018 at four metres deep. It uses wave dynamics to determine the quantity of energy flowing through a wave. The correct description of this complex energy flow is used, for example, to optimise mathematical climate models. A laser apparatus called the "AirSeaPix" is therefore affixed to the eleven-metre-tall measurement pole. This way the scientists can gather knowledge on the formation of hurricanes. The measurement pole in the Baltic Sea continuously records waves and the flow of mist droplets, but oxygen and carbon dioxide content in the sea can also be determined using the devices.

Searching for pollutants in the Baltic Sea

Dr Jochen Horstmann releases a drifter

The LUDWIG PRANDTL in the Media

Clockwork Ocean

Many measurement campaigns in which the PRANDTL has participated are not publicised at all or only to a very limited extent. One media appearance, however, made the research vessel famous: “Clockwork Ocean” in June of 2016. During this expedition, a Zeppelin was used for the first time in the history of sea and coastal research to study ocean eddies. The aim was to determine what role these eddies play in energy transport and in the sea’s food chain. The scientists measured the temperature differences at the ocean’s surface and determined the water’s colour spectrum. Measurement equipment, such as the drifter, the Acoustic Doppler Current Profiler (ADCP), and the towed instrument chain supported the research ships LUDWIG PRANDTL, EDDY and the ELISABETH MANN-BORGESE while studying the eddies. A great deal of data was collected, and an eddy could be measured for the first time, from its emergence to its collapse.

www.clockwork-ocean.com

Coastal Research on Tour

LUDWIG PRANDTL has greeted numerous visitors during its “Coastal Research on Tour” events. Since 2009, coastal research work has been presented annually on the ship in ports along the German North Sea and Baltic Sea coasts. Everyone—whether young or old—can take a free tour during the “Open Ship”, get a glimpse of the research and ask the scientists questions. But there’s also something hands-on to do: the guests can carry out measurements themselves and get acquainted with coastal research in an entirely different way. This always provides a great sense of enthusiasm and participation.

www.hzg.de/openship

Captain Helmut Bornhöft has been steering the ship for decades

Searching for Gottfried

It's hard to believe, but there's a treasure in the Elbe estuary near Cuxhaven. In March 1822, a ship named the GOTTFRIED sank with a cargo that included hundreds of ancient Egyptian treasures. The treasure has never been found - neither has the ship. In the summer of 2010, the HZG made the LUDWIG PRANDTL available to Schleswig-Holstein's state archaeological office to locate the GOTTFRIED's cargo using a novel hydroacoustic method. One type of equipment used for the treasure hunt was a side-scan sonar. It transmits sound signals that are reflected back from the seabed to locate conspicuous objects. Using the sediment echo sounder, a complete image of the seafloor can be produced on the computer. Under optimal conditions - no wind, no waves and with bright weather - the researchers can even look into the seafloor. The search did not result in the discovery for which they had hoped. The experts, however, are not giving up and are continuing to search for the ghost ship and its valuable cargo.

https://www.youtube.com/watch?v=4vGLrZrOwjM

Now in charge of the ship: Captains Heiko Gerbatsch and Marco Schacht

Good News for the German Research Fleet: The Federal Government Supports Construction of a New Research Vessel, the LUDWIG PRANDTL II

Due to the age of the current ship, its replacement is necessary with a new vessel. The LUDWIG PRANDTL II is to cover a broad, interdisciplinary spectrum of coastal research, materials research, polymer science and digitisation. It is therefore to be used in a variety of ways by the HZG and its partners for research and teaching. Construction of the new vessel will cost approximately 13.5 million Euros. A wet laboratory, electrical laboratory and external laboratory as well as a lab for hydrogen technology is planned for the LUDWIG PRANDTL II. There will also be observation technologies with autonomous measurement devices, instruments for flow measurements and various other systems that can be used flexibly. The ship's propulsion design will use a metal hydride storage tank developed in the materials research division at the HZG in Geesthacht. Membranes developed by the polymer research division are to be used to minimise pollutant emissions from engines based on heavy oil and diesel combustion by treating the charge air. In addition, the research vessel is to be equipped with a completely new information system and data management. The keel-laying ceremony is planned for 2022.

More info about LUDWIG PRANDTL II:

hzg.de/new-research-vessel

Photos ©HZG/Christian Schmid, ©HZG/Gesa Seidel, ©HZG/Emma Lefebvre, ©HZG/Patrick Kalb-Rottmann, ©HZG/Sabine-Billerbeck, ©private

Author: Charleen Schwabe (HZG)

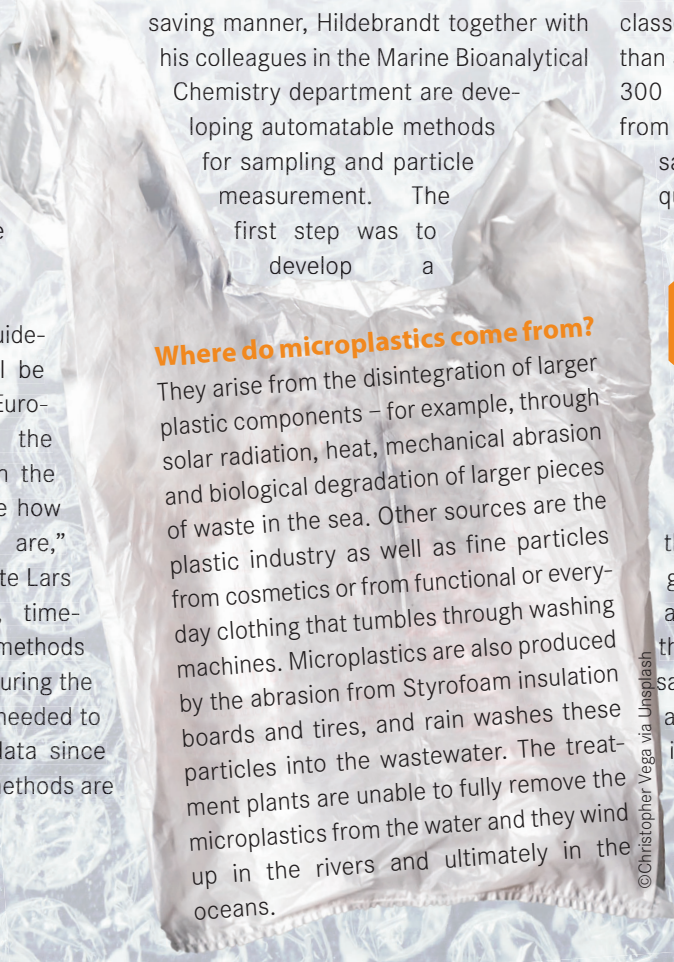
Detective Work: Coastal Researchers on the Hunt for Microplastics

Plastic waste is a serious problem for our oceans. There are already more than 5.25 trillion plastic particles swimming in the world's oceans. According to estimates, approximately fourteen per cent of the plastic floating in the water's upper layers consists of microplastic particles. Using new measurement instruments and improved analytics, HZG coastal researchers are working on a standardisable method for measuring these microplastics. The new methodology aims to determine precisely and far more quickly and effectively how many small particles and which types of plastic are present. After all, not enough is known yet about the dangers of fine particulate plastic waste to the environment and humans.

Microplastic particles are no larger than a half centimetre and can be as small as a micrometre, fifty to eighty times smaller than the diameter of a human hair. They are created in part from the disintegration of larger plastic pieces in the sea or wind up via the wastewater in the rivers and subsequently in the oceans. Scientists have detected the alarmingly ecological ubiquity and longevity of plastic particles worldwide. The results of many studies, however, are only comparable to a limited extent so that the current overall situation can hardly be estimated reliably.

"Hopefully new analytical guidelines and legal measures will be provided in the future, at the European level, to determine the proportion of microplastics in the global oceans and to estimate how hazar-dous the substances are," explains HZG doctoral candidate Lars Hildebrandt. "More precise, time-efficient and robust analytical methods as well as technology for measuring the microplastics are desperately needed to generate more comparable data since currently too many different methods are used." Natural particles, such as grains of sand, are often visually identified as plastic particles. Erroneous results also arise from unsuitable methods for sampling and sample processing in the laboratory, which presents another huge problem.

To measure the occurring plastic in the environment in a reliable, valid and time-saving manner, Hildebrandt together with his colleagues in the Marine Bioanalytical Chemistry department are developing automatable methods for sampling and particle measurement. The first step was to develop a device for obtaining the particles from the sea. The researchers are using the "Geesthacht Inert Microplastic Fractionator" (GIMPF) for the first time, carrying out sampling on board the SONNE research vessel in the Indian Ocean and on the LUDWIG PRANDTL in the Elbe estuary. The devices use two stainless steel cartridge filters to separate particles of two size classes from the seawater. Particles larger than 300 micrometres and between 10 to 300 micrometres can thus be enriched from large volumes of water. After the sampling the particles are subsequently analysed in the laboratory.



©Christopher Vega via Unsplash

Where do microplastics come from?

They arise from the disintegration of larger plastic components – for example, through solar radiation, heat, mechanical abrasion and biological degradation of larger pieces of waste in the sea. Other sources are the plastic industry as well as fine particles from cosmetics or from functional or everyday clothing that tumbles through washing machines. Microplastics are also produced by the abrasion from Styrofoam insulation boards and tires, and rain washes these particles into the wastewater. The treatment plants are unable to fully remove the microplastics from the water and they wind up in the rivers and ultimately in the oceans.

Fadi El Gareb: Microplastics are ubiquitous

Microplastics are so ubiquitous, that containers, devices and even gloves, dust in the air and clothing can act as particle sources. "To ensure that only the microplastics from the sample are measured, the microplastic analysts prepared the laboratories and instruments accordingly. They also, for example, created the GIMPF en-

tirely out of stainless steel and aluminium," explains master's student Fadi El Gareb, who carried out sampling on board the SONNE in 2019 with Prof Kay-Christian Emeis, coastal research institute director. To minimise contamination, all work was done in small, mobile clean benches, equipped with special filters so that the incoming air was continuously filtered of particles. Glass containers were rinsed beforehand with filtered alcohol, seals were coated with Teflon and the filters and all other equipment were thoroughly rinsed after each sampling.

The work continues on land: here the particles are studied using optical methods, but beforehand the unwanted natural organic and inorganic components must be removed from the sample using an enzymatic-chemical treatment as well as a physical separation method.

For the subsequent detective work, the scientists used another new technique: they further developed a spectroscopic method with which the varying types of plastics can be more securely and quickly identified. Hildebrandt says, "We studied the samples using a new quantum cascade laser. The laser lights up the samples with infrared light and analyses the light absorption through the particles. The different particles reflect with different intensities at varying wavelengths depending on their chemical composition. This is how we determine a type of molecular fingerprint for individual particles." What is new about this method is that, on the one hand, the very fast infrared source takes one second to produce a spectrum, whereas with standard instruments it takes more than thirty seconds. On the other, the spectral assessment is carried out in an automated process so that the researchers no longer need to compare the spectra manually with a substance database as they did before.

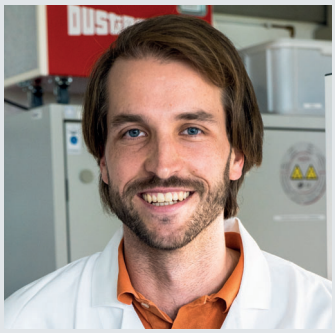
"The new method is much quicker and more powerful than traditional infrared spectroscopy and can therefore analyse a far greater number of particle samples in the same amount of time," explains Hildebrandt. The fully automated analysis of eight hundred particles and comparison of the produced spectra with the database takes approximately one hour. In comparison, the standard assessment methods used so far can take days and the error rate is higher, as the subjective spectra classification depends on the respective scientist.

Lars Hildebrandt: Our new method is much quicker and more powerful than classical methods.

The HZG scientists still need a bit of time for analysis until their final results are available. In December, an additional large research campaign has been carried out with the GIMPF in the Atlantic Ocean.

After all, it is still unclear what damage microplastics can do to the environment and to human beings. The question as to the amount of microplastics in the environment also cannot be answered. Data and standardised evaluation criteria are missing on how much microplastic the environment can tolerate or what possible biological effects develop. The new methods utilised by the Geesthacht microplastic detectives could help to provide answers.

Author: Heidrun Hillen (HZG)



©HZG/Steffen Niemann

ABOUT:
Doctoral candidate **Lars Hildebrandt** has been working at the HZG since 2018 in the Marine Bioanalytical Chemistry department. Through his dissertation, the chemist aims to help explain the environmental role of microplastics.

©private

ABOUT:
Master's student **Fadi El Gareb** is studying geosciences at the University of Hamburg. Together with the HZG coastal researcher Professor Kay-Christian Emeis, he participated in a research expedition on the SONNE in 2019, travelling from Hong Kong to Mauritius, across the Indian Ocean.

The Marine Bioanalytical Chemistry department, under the leadership of HZG coastal researcher Daniel Pröfrock, possesses extensive experience in the field of ultra-trace analysis. In addition to investigating microplastics, the department's research focus lies in the investigation of new inorganic pollutants and their role and transportin the aquatic and marine environment.

Background: ©David Maier via Unsplash

CO_2: Food for Chlorella sorokiniana marrakechensis

Geesthacht's polymer research membranes used for the Algae House

Gas bubbles flow throughout the bioenergy façade filled with algae and liquid, which usually appears green. But the Algae House isn't just an eye catcher from the outside: the technology inside is also extraordinary. Using membranes from the HZG's Institute of Polymer Research, carbon dioxide is separated from the flue gas of the in-house gas heating system - and is used to feed the algae.

Thorsten Wolff again checks whether the module has been correctly connected. Then it all begins: the first real working application for the new membrane module in the Algae House. The process engineer from the Geesthacht Polymer Research unit has already been involved in the project for six years. The system works very robustly, but something needs to be changed every now and then in order to attain the most from it. For example, experiments are conducted with different types of algae. Most recently, the operator wanted to cultivate rapidly growing algae from North Africa: Chlorella sorokiniana marrakechensis.

The new-membrane, like its predecessor, consists of several polymer layers. The actual separation layer is made up of the "PolyActive" block copolymer. Using the membranes produced in Geesthacht, a large portion of the carbon dioxide (CO_2) can be separated from the conventional gas heating's flue gas. Wolff explains, "The flue gas consists of ten per cent carbon dioxide with a residual oxygen content of five per cent, while the rest is nitrogen and water vapour. The membranes allow CO_2 and water vapour to pass through particularly well, but they are not one hundred per cent selective. We therefore cannot separate CO_2 exclusively. We have, however, managed to concentrate a large portion of the CO_2 so that we can obtain a gas mixture that consists of forty per cent CO_2. This mixture is introduced into the algae liquid, and the rest is emitted outside, via the chimney."

Through photosynthesis - that is, with the help of sunlight - the algae utilize CO_2 and water and convert them into biomass and oxygen. "The new North African algae grow especially quickly and therefore require a great deal of carbon. This is why we have now increased the membrane surface by half and adapted the module. A total of 104 membrane envelopes are installed within it. This is how a great deal more CO_2 can now be separated than

About the Algae House

The Algae House was constructed as part of the International Building Exhibition, which took place in Hamburg-Wilhelmsburg in 2013. The biotechnology firm SSC Strategic Science Consult GmbH operates the innovative building, which includes twelve flats on five floors. Dr Martin Kerner, its managing director, completed his "Habilitation" in environmental science at the GKSS (today HZG) in 1996

The Algae House's bioenergy façade consists of 129 plate-shaped modules, which contain 3,500 litres of nutrient fluid over an area of 200 square metres. The individual modules are constructed like an insulated glass pane made of four layers and measure approximately ten centimetres thick. The internal gap filled with nutrient solution measures only two centimetres thick. Air bubbles constantly mix the algae in the solution so that all algae cells receive an even share of light.

Various research and development projects have been carried out on the Algae House since 2013. For example, algae have been shown to help in wastewater treatment by breaking down drug residues from the water. Another project involved developing a novel extraction process with which biologically active substances from biomass could be separated from the living algae and enriched during cultivation. Today the Algae House includes technology that is not only sustainable, but also possesses economic potential and is ready for the commercial market. The bioenergy façades are marketed through the SSC subsidiary cellparc GmbH.

Photos: ©HZG/Christian Schmid

Left: Engineer Thorsten Wolff installed the new membrane module (centre of image) in the boiler room of the Algae House, which is operated by Dr Martin Kerner.

Above: The Algae House in Hamburg-Wilhelmsburg is an absolute eye-catcher.

Right: Thorsten Wolff has been working at the HZG in Geesthacht since he completed his master's thesis in 2003.

before," explains Thorsten Wolff. The membrane surface measures approximately twelve square metres.

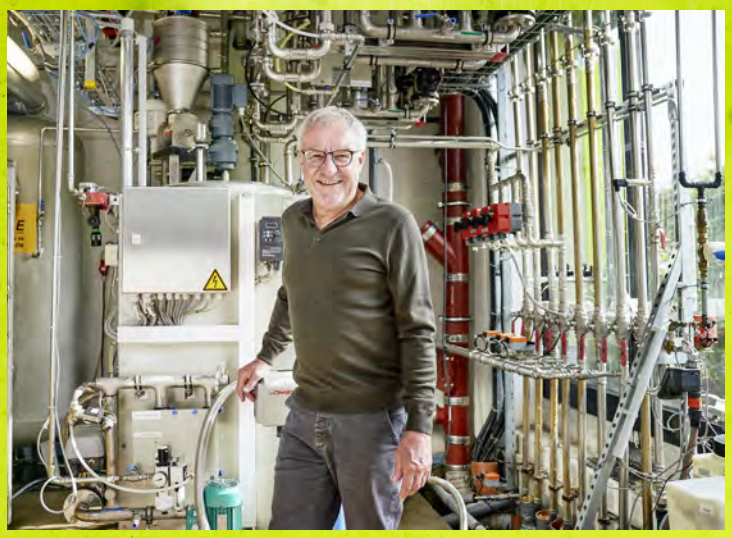
At the Institute of Polymer Research, the scientists map the entire process chain, which is a unique feature in this field. This includes computer simulations, which have taken many years to develop, and numerous experiments. "We are constantly comparing the measurement values from our tests with the digital models. If the data matches, we know that we're on the right path and that the module is working flawlessly."

The membranes are produced at the in-house membrane production hall and are installed in self-designed pressure vessels, so called membrane modules. "The combination of process simulation, experiments and pilot studies using HZG's pilot plants as well as the subsequent integration into operational systems makes the work here so exciting," says Thorsten Wolff.

The algae serve as a valuable raw material in diverse industries, such as food, cosmetics and the pharmaceutical sector. Thirty to fifty per cent of all algae biomass is harvested daily. This was also a reason for the new algae: more rapid and increased growth leads to more biomass, which then can be utilised. During the operational period between March and October, the fully automatic system runs up to ten hours a day in several cycles. Ten cubic metres of flue gas are filtered per hour, resulting in one cubic meter of CO_2-rich gas as "algae feed".

There is an additional bonus for the climate: the bioenergy façade works like a solar thermal facility, generating heat, which has been used since 2016 to fully supply the building with warm water and heating. The Algae House's sustainable technology is now marketed internationally. "The Algae House is a unique and very beautiful project. I'm really happy that we can contribute in part with our membranes," says Thorsten Wolff. "In addition, it always feels good to see how research can make its way into very concrete applications."

Author: Gesa Seidel (HZG)



©HZG/Christian Schmid

Dr Martin Kerner completed his "Habilitation" in environmental science at the GKSS (now HZG) in 1996. Today Kerner is managing director of the biotechnology firm SSC Strategic Science Consult, which operates the Algae House in Hamburg.

©HZG/Gesa Seidel

The module developed at the Institute of Polymer Research measures 30 centimetres in diameter and 50 centimetres in height; inside it houses 104 membrane pockets layered on top of one another.

Why is Internationality so Important for Research?

With the #BlackLivesMatter movement in focus and in a climate in which some of us question our own national or cultural identities, we would like to set an example as an internationally positioned research centre: The approximately 1,000 employees at our locations and branch offices come from over 55 nations. Research and science can only work in mutual exchange. There is no place for racism and discrimination at HZG.

©HZG/Charleen Schwabe

Linda van Garderen, PhD student, Coastal Impacts and Paleoclimate

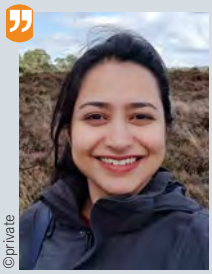
As our personal frame of reference is created by our upbringing and culture, it adds incredible value to have a group of scientists with various perspectives. We all see a different part of the same drawing, and we need each other to get a complete view. This counts for internationality as well as integration among specialists. Besides, it is great fun to learn about and mix in cultures and habits on the work floor. Add some creative thinking to that and we basically have a scientific (and non-aggressive) version of the Avengers, all bringing our own strengths into the mix.

Dr Jorge dos Santos, Scientist, Solid State Joining Processes

©HZG/Gesa Seidel

The Solid-State Joining Processes department at HZG received approximately 400 foreign students (trainees, bachelors, MSc), PhD candidates and postdocs since the year 2000. They came from all corners of the Earth and enriched the department as well as HZG with their culture, creativity, ingenuity and hard work. Their approach and methodology to address scientific and technical questions have in so many cases opened our eyes to solutions and ideas, which would probably not have occurred to us. This “other way of seeing things” is a direct result of our cultural legacy, a sum of all experiences and events, from our infancy to maturity, which is embedded in our intellectual DNA. Hence, diversity in science – fundamental or applied – is today a matter of fact and cannot be disregarded as a driving element of the system. Thankfully, in scientific circles, diversity is a "given" and open racism and discrimination are an exception.

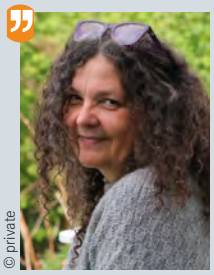
Dr Kirti Sankhala, Scientist, Membranes - Materials and Processes



©private

Internationality in research: a cherished mechanism for advancing knowledge, strengthening research capability and gaining new perspectives with a vision to serve people around the globe. International research centres like HZG enrich the research and learning environment. Internationality not only increases the social and cultural diversity but also helps the team to understand and benefit from the inherent cultural and linguistic differences. It gives clarity to the researchers about their strengths and weaknesses and helps to fill each other's knowledge gaps. Additionally, advancement of technology becomes more meaningful when it is accessible to all. Being an early stage researcher, I would add that international collaboration enables us to access additional, often specific expertise on research and build relationships with others in the field.

Prof Corinna Schrum, Head of System Analysis and Modelling



© private

Science is generally independent of nationality and ideally free of national interests. International scientific exchange and cooperation create new ideas and increases the space for creativity. This is especially true for coastal, marine and climate research which are addressing global challenges. These challenges can only be handled sensibly and efficiently in international cooperation. Internationality in research and education is the basic prerequisite for building the necessary understanding to overcome cultural barriers. Only in this way can we make meaningful contributions to this global challenge.

Storms in the north: is it simply the weather or are we already experiencing climate change?

You can now have a look online at sturm-monitor.de

Storms cause damage resulting in immense financial losses and pose safety risks. Where, when and how often storms occur in Germany is difficult to predict. The HZG's new "Storm Monitor" website, however, will clarify whether a severe storm is still a normal weather event or can already be attributed to climate change. The Storm Monitor compares the current storm situation with wind data from the past seven decades. The site shows how many storms have occurred during the current season or in the past month and to what extent the number deviates from the long-term trend. www.sturm-monitor.de **www.sturm-monitor.de**

New handbook compiles various decision-relevant research results on climate change in northern Germany.

The new handbook on Climate Change in Northern Germany is extracted from the Hamburg Climate Report. Climate warming has also accelerated in Northern Germany and could even increase in the future through ongoing intensive greenhouse emissions. In the handbook, consequences of climate change on important supply bases and infrastructure are identified. Moreover, options for adapting to a changing climate are summarized. The book clarifies that the consequences of climate change and the 1.5C degree target laid out in the Paris Climate Agreement require a comprehensive change in policy, economy and society.

The book is published by Dr Insa Meinke, head of the Norddeutschen Küsten- und Klimabüros at the HZG. The free e-book can be viewed or downloaded at:

www.hzg.de/norddeutschland-im-klimawandel

Climate in the North: New Book and Web Tool

www.sturm-monitor.de

www.kuesten-klimabuero.de