Activities report 2016–2017

National Center of Competence in Research Bio-Inspired Materials

Swiss National Science Foundation

BIO-INSPIRED MATERIALS
NATIONAL CENTER OF COMPETENCE IN RESEARCH

Who we are

The National Center of Competence in Research (NCCR) Bio-Inspired Materials was launched in June 2014 with the vision of becoming an internationally recognized interdisciplinary hub for research, education, and innovation in the domain of "smart" bio-inspired materials.

We take inspiration from natural materials to establish design rules and strategies for the creation of macromolecular and nanomaterial-based building blocks and their assembly into complex, hierarchically ordered stimuli-responsive materials with new and interesting properties. We seek to develop a predictive understanding of the interactions of these materials with living cells and use this knowledge to develop innovative applications.

Our research is organized in three modules that focus on mechanically responsive materials, responsive materials created by self-assembly, and the interactions of responsive materials with living cells. Each of these modules tackles major unsolved problems, and requires an interdisciplinary research approach.

Our research activities are complemented with many programs that integrate research and education, support structured knowledge and technology transfer, and promote equal opportunities in science.

An annual report early in the year?

The business year of the NCCR Bio-Inspired Materials runs from June to the end of May, which explains why this report is published at a different time of the year to most others. All statistical data are reported for March 1, in accordance with the reporting requirements of our funding agency, the Swiss National Science Foundation.

Table of contents

5
Message from the directors

The NCCR Bio-Inspired Materials continues to expand the scope of its activities, with new collaborations and initiatives.

7
Research

Some of our most recent research projects demonstrate how nanoparticles could be used to combat viruses, seek to understand the properties of novel exotic materials, and lead to the development of functional microcapsules.

26
Initiatives

From developing interest of youngsters in science all the way to encouraging entrepreneurial vocations.

Content

Message from the directors

Dear readers

Bio-inspired design is a general approach in which nature's principles are applied to develop new technical solutions, often in domains that have traditionally been thought to have little in common with biology. This concept is exploited in areas that range from robotics to architecture to computing.

It is also a useful framework for creating artificial materials systems that emulate some of the intriguing and unusual properties and functions found in animals and plants.

Based on this premise, the NCCR Bio-inspired Materials was launched in 2014 with the goal of becoming an internationally recognized competence center in research, innovation, and education in the domain of materials whose design and function are inspired by nature.

Since its start, the Center has seen continuous quantitative and qualitative growth in all areas of activity. Last year, we welcomed Professors Michael Mayer (Biophysics, Adolphe Merkle Institute) and Aleksandra Radenovic (Nanobiology, EPFL) to the team, and their groups began contributing their expertise on protein nanopores engineering and nanoscale cell imaging, respectively. The Center's overall number of participants increased to nearly 100 and we published twice as many scientific publications as in the previous reporting year. The fraction of papers co-authored by two or more of our NCCR groups is continuously growing and has reached about a third of our publications, reflecting the collaborative nature of our research projects.

The number of co-operations with external partners, most of which are international, increased to over 100. A group of NCCR professors, led by Professor Nico Bruns, and partners at the universities of Cambridge (UK) and Freiburg (Germany) as well as at several companies and non-academic institutions won a highly competitive European Innovative Training Network grant on plant-inspired materials and surfaces. Meanwhile, in another boost for bio-inspired research, NCCR professors from the Adolphe Merkle Institute partnered with scientists at Case Western Reserve University in Cleveland and the University of Chicago (both USA) to study and develop materials that mimic the structure and function of tough caddisfly silk, the adaptable skin of sea cucumbers, and other biomaterials. These efforts are supported by jointly awarded grants from the US and Swiss National Science Foundations. Both these networks leverage our Center's research capacities, and provide PhD students with meaningful training experiences. Similarly, our training activities include an international exchange program for PhD students, a new master's program, and undergraduate research internships.

Naturally, this report also highlights some of our research activities. We selected projects that we deem representative of the broad scope and interdisciplinary nature of our research endeavors, ranging from mechanochemistry to the behavior of synthetic nanoparticles in cells. We have chosen as well to showcase technological outcomes that promise innovation in nanoparticle sensing and microfluidic fabrication tools.

We hope that this report conveys our team's passion and enthusiasm for our work, and that you will enjoy reading about our achievements.

Christoph Weder & Curzio Rüegg
Directors NCCR Bio-Inspired Materials

A three-dimensional model of a white beetle shell.

Research

What we do

The overarching research theme of the NCCR Bio-Inspired Materials is to use inspiration from nature for the design of artificial materials that can change their properties on command, so to speak, or, in other words, in response to an external stimulus. These materials, sometimes referred to as "smart" or "intelligent", are of fundamental scientific interest and potentially useful in countless applications that range from climate control for buildings to drug delivery systems in the body.

In the recent past, scientists have begun to consider nature's principles as inspiration for the design of artificial materials with intriguing stimuli-responsive properties. Previous examples of materials studied by individual research groups that belong to the Center include mechanically adaptive nanocomposites inspired by sea cucumbers, drug-delivery nanoparticles that mimic the structure and stealth behavior of viruses, and optical elements that emulate the nanoscale patterns found in butterfly wings.

With the aim of carrying out paradigm-changing scientific breakthroughs and harnessing the enormous innovation potential in this domain, the Center has developed into a large-scale interdisciplinary effort that merges competences in chemistry, physics, materials science, biology, and medicine.

At the start, our research was organized in three modules that emphasized research on mechanically responsive materials, responsive materials made by self-assembly, and the interactions of responsive materials with living cells, respectively. As hoped and expected, however, the boundaries between the original projects and modules have started to blur, and several new research endeavors were launched that take full advantage of the Center's interdisciplinary environment.

Interactions

A better understanding of nanoparticle integrity inside cells

NCCR Bio-Inspired Materials researchers at the Adolphe Merkle Institute have highlighted the need to apply complementary analysis methods to study nanoparticle behavior inside cells, pointing to shortfalls in previously used techniques.

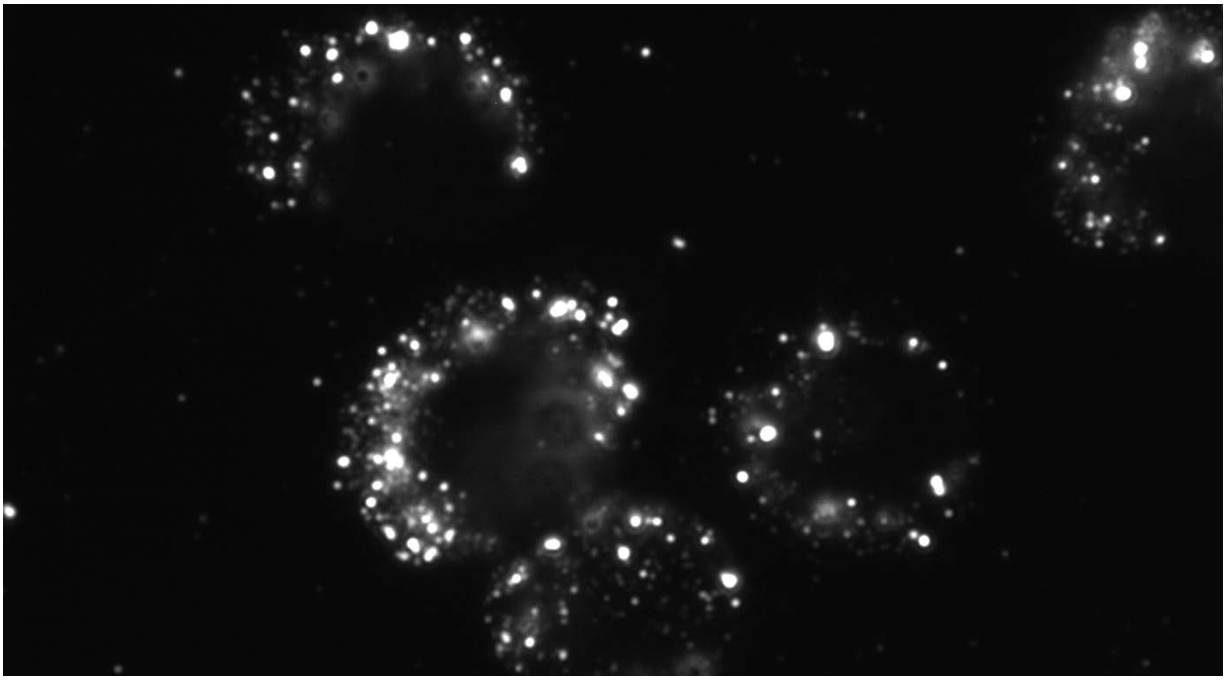
Nanomedicine promises better, more efficient, and more affordable healthcare. It could also provide solutions to illnesses such as cancers, cardiovascular diseases, multiple sclerosis, neurological afflictions such as Alzheimer's and Parkinson's, and diabetes. It is also hoped that research in nanomedicine will help researchers understand more about how the human body functions at the molecular and nano-scales, allowing for the production of more targeted treatments. The global market for nanomedicine is estimated to increase substantially during the next decade, reaching over $350 billion by 2030.

However, little is currently known about the way in which nanoparticles interact with the human body. Their size allows them to be taken up by cells, but their behavior once inside is still being documented, and few studies have considered the effects of the intracellular environment on nanoparticles.

For the past three years, NCCR Bio-Inspired Materials PhD student Ana Milosevic and her colleagues have been investigating the fate of fluorescently encoded gold nanoparticles (AuNPs) after cellular uptake, potential particle aggregation, and the integrity of the surrounding polymer layer into which a fluorophore has been integrated. The research, among the first of its kind, has focused in particular on digestive organelles known as lysosomes, acidic and confined spaces in cells where most of the observed nanoparticles accumulate after uptake.

"Lysosomes play a significant role in the fate of nanoparticles, since they are the last resting place of internalized nanoparticles," says Milosevic. "Lysosomes digest internalized substances and recycle the remaining components for further use. If you take into consideration the role of lysosomes, with their low pH, high salinity, and proteolytic enzymes, they constitute a rather hostile environment for anything other than biomolecules."

Gold nanoparticles were chosen as they are frequently used in biomedical research. Their size and shape can be manipulated, and other traits, such as their optical properties, biocompatibility, and potential for surface functionalization, are considered highly desirable. AuNPs can also be functionalized with polymers, many of which in-



Fluorescently encoded gold nanoparticles after cellular uptake.

clude fluorescent dyes, making them a promising imaging method for a variety of biological in vivo and in vitro applications.

"Fluorescent signals are a useful tool in biology and medicine to analyze nanoparticle uptake by cells and their intracellular fate using techniques such as fluorescent microscopy and flow cytometry," explains NCCR Principal Investigator Professor Barbara Rothen-Rutishauser.

So far, results have shown that the high salt content and low pH environment of the lysosomes strongly affect the stability and integrity of negatively-charged polymer-grafted AuNPs. This leads to aggregation and conformational changes of the polymer, followed by a loss of the fluorescence property of the fluorophore. Nanoparticles can undergo significant changes as a result of the lysosomes' specific environment.

NCCR researchers say that it is important now to investigate more thoroughly the effects of a specific biological environment on all of the components that researchers rely on to detect a nanoparticle, including fluorescence.

Reference

Milosevic, A. M.; Rodriguez-Lorenzo, L.; Balog, S.; Monnier, C. A.; Petri-Fink, A.; Rothen-Rutishauser, B. Assessing the stability of fluorescently encoded nanoparticles in lysosomes by using complementary methods. Angewandte Chemie 2017, 13567

Protective

Microcapsules to shield precious materials

Sensitive materials are prone to degradation and require protection from their surrounding environment. NCCR Bio-Inspired Materials researchers at Zurich's Federal Institute of Technology (ETHZ) are investigating methods to encapsulate products as small as a human hair.

Active ingredients need to be kept stable to avoid premature degradation. To preserve food, for instance, aluminum foil is useful to prevent drying and oxidation. In materials science, the goal is to protect materials at a very small scale, just a few micrometers in diameter.

NCCR Principal Investigator Professor André Studart and his team have been working on micro-encapsulation of different materials. In a first step, they produced a small droplet containing the materials that require protection, which is then enclosed in a second polymer droplet. By solidifying the outer droplet, they obtained a microcapsule with a liquid inner core. In a second stage, they studied different release triggers for the microcapsules, such as a temperature, mechanical force, magnetic force, or chemical release.

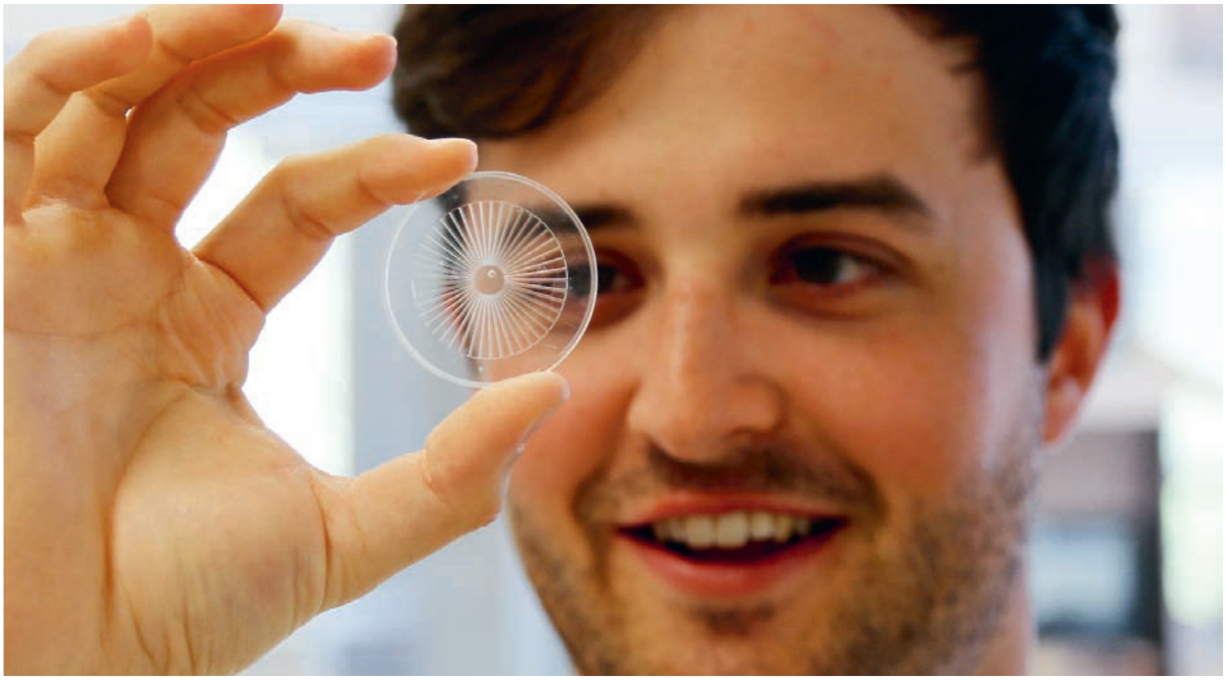
This research is relevant for the pharmaceutical, cosmetic, and food industries, where active substances often need to be protected from their surroundings. A drug, for example, should be protected from the acidic environment of the stomach and only release its active ingredient at a later stage in the digestive tract.

Studart's capsules are produced via microfluidics, a technique where liquids are pushed through tiny microchannels, enabling the mixing, reaction, and emulsification of different fluids. This method is extremely precise, allowing for the creation of droplets and capsules of a standard size.

However, production is limited to small amounts, which is interesting in the laboratory, but not relevant for industrial purposes. To overcome this hurdle, NCCR researchers broke convention by using a new approach called step emulsification. They developed a scalable microfluidic chip that enables high output production of monodisperse emulsions thanks to the device's hundreds of linearly parallelized droplet makers.

The chip can be cleaned for nearly unlimited use and permits alternating production of oil-in-water and water-in-oil emulsions. The combined high throughput, and the chemical and thermal stability offered by the device should enable production of monodisperse functional materials for large-scale applications.

With this approach, the researchers have been able to increase the throughput of functional mi-



PhD student Alessandro Ofner holds one of the microfluidic devices developed in the Studart laboratory.

crocapsules by one to two orders of magnitude. Studart believes this approach could be useful for industrial applications to, for example, encapsulate drugs in medication, anti-aging substances in skin creams, or aromas in common food products.

> "With this approach we increase the throughput of functional microcapsules by one or two orders of magnitude." Alessandro Ofner

Given the potential of the device, Studart team member Alessandro Ofner was awarded the NCCR's first Proof of Concept grant, worth CHF 20,000, for his project "Massive Production of Monodisperse Microcapsules with a 3D Microfluidic Device."

The Proof of Concept Grants provide funds for short-term projects (up to three months) with a potential for application, for example prototyping, development of an advanced proof-of-concept, benchmarking of inventions with existing technologies, demonstration of specific applications, assessment of pre-industrial feasibility, and/or identification of market opportunities.

Ofner was able to build a new prototype of a highly-parallelized microfluidic device. This device allows the fabrication of monodisperse micro-droplets and -particles 100 times faster than with the best conventional devices, covering a droplet range of 40 – 400 micrometers. The research team is now setting up industrial collaborations to test the encapsulation of materials for relevant applications.

Reference

Ofner, A.; Moore, D. G.; Rühs, P. A.; Schwendimann, P.; Eggersdorfer, M.; Amstad, E.; Weitz, D. A.; Studart, A. R. High-throughput step emulsification for the production of functional materials using a glass microfluidic device. Macromolecular Chemistry and Physics 2017, 218, 1600472

Stretchy

Exotic materials defy expectations

NCCR researchers are investigating novel materials that defy most people's perception of the world around us. These so–called auxetic materials typically expand when stretched, contradicting what experience tells us they should do.

Auxetic materials first became prominent three decades ago, when an American researcher described a polymer foam that expanded in a direction perpendicular to the one in which it was being stretched. This is the typical behavior of a material characterized by a so-called negative Poisson's ratio (NPR). The advantages of these "exotic" materials are, for example, their strength and their capacity to absorb shocks better than non-auxetic materials.

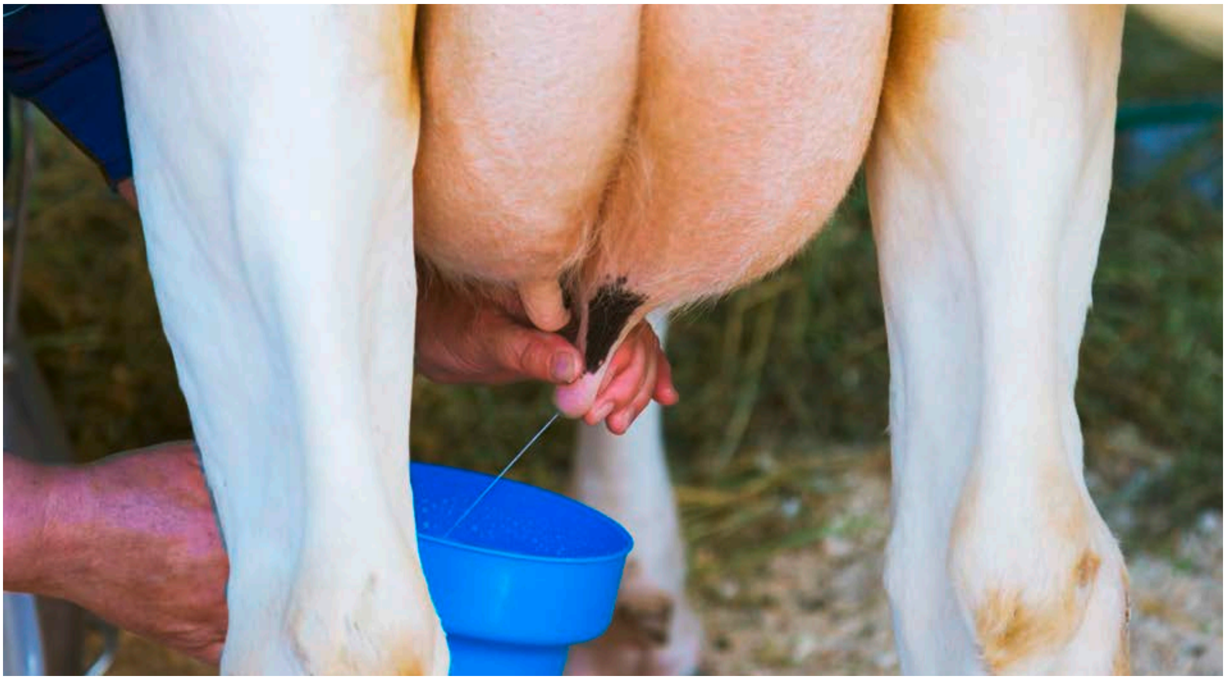
As a matter of fact, auxetic materials are quite common in nature, ranging from iron pyrite, also known as fool's gold, to cat skin, cow teat skin, and cancellous bone. A recent example of an application inspired by nature is the creation of helmets that mimic the crash-resistant properties of pomelo fruit. Further potential applications include shock absorbers, piezoelectric sensors, and others in the biomedical field, such as fibers for bandages, wound pressure pads, artificial blood vessels, and materials for tissue engineering.

The properties of auxetic materials are dependent on their internal structure. Research at the smallest scales is relevant because these materials suffer from relatively poor tensile stiffness and strength. To overcome this, NCCR researchers are seeking to control auxetic behavior at the molecular level.

Researchers have registered several successes in synthesizing auxetic materials down to the smallest sizes. However, this remains the exception rather than the rule.

"In a molecular auxetic material, we start off with a densely packed polymeric structure," says NCCR Principal Investigator Professor Andreas Kilbinger. "When stretched, the density of the structure must be reduced in order to observe an auxetic effect. We must therefore create a less efficient (less dense) packing upon stretching the material. As there is no gas flow from the outside to the inside of the material, the sum of all small structural rearrangements within the auxetic material must add up in theory to a macroscopically observable effect."

NCCR Bio-Inspired Materials staff at the University of Fribourg and the University of Geneva have been exploring the design and the synthesis of polymeric molecular auxetic materials using oligoaramides as building units. One of their well-known relatives is Kevlar, a polyaramid that is used for bullet-proof vests, protective clothing, and sports equipment, for instance.



A cow teat is an example of a natural auxetic material.

"Oligomeric aromatic amides are easy to synthesize and shape persistent, which means they keep their shape or have predictable shapes," explains Kilbinger. "The shape-predictability allows the synthesis of geometric shapes on the nanoscopic length-scale."

> "The sum of all small structural rearrangements within the auxetic material must add up, in theory, to a macroscopically observable effect." Andreas Kilbinger

So far, the researchers have been stretching model compounds using a mechanical stretching device that can fit into a UV/vis spectrometer and observing the re-arrangement of the geometric shapes within the compounds using polarized UV-light absorption. "This allows us to tell in which direction rod-like molecules arrange when we stretch a material," adds Kilbinger.

Results have been reasonably encouraging. "When the rod-like molecules are diluted in a stretchable material, we can observe the re-arrangement effect," says the NCCR PI, who warns, though, that there are obstacles to overcome. "To observe a macroscopic auxetic effect, the concentrations of that rod would need to be much higher. And once the concentrations are higher, the stretchability is lost."

Kilbinger is optimistic that a molecular auxetic can be synthesized. Nevertheless, even if this cannot be achieved, he says that there is "a lot of fundamental science to be studied and learned on the way."

Thin-skinned

Deconstructing a beetle shell

In nature, the hallmark of many insects is their vibrant colors. Some of these colors, the shimmering greens and blues found in some butterflies and beetles, for example, are the result of ordered nano-structures present in their outer shells or in the scales on their wings. The color white, however, is less common, and for a long time, how the color, particularly that of white beetles, comes about was not well understood.

Cyphochilus beetles from southeastern Asia, for instance, are as white as paper, but their color-producing layer is approximately 100 times thinner. NCCR researchers at the Adolphe Merkle Institute, together with scientists from the Swiss Light Source and the universities of Hamburg, Princeton, and Cambridge, have been investigating how these beetles manage to scatter light of all colors equally with just a very thin and light-weight shell.

White is relatively difficult to produce. A single color being reflected off a surface is usually the result of one event: light of a specific wavelength not being absorbed by the object it hits, but being reflected towards the observer. A colored film such as a soap bubble can therefore be extremely thin, somewhere on the hundred nanometer scale (comparable to a fraction of the light wavelength).

White, on the other hand, is a combination of all colors, meaning that light of all wavelengths is being scattered by the material. To succeed at doing this, a material such as paper needs to be thicker.

So far, most studies of structural color in nature concern periodic arrays, which create color through the interference of light. The color white, however, relies on the multiple scattering of light within a randomly structured medium, which randomizes the direction and phase of incident light. Opaque white materials must therefore be much thicker than periodic structures.

Given that flying insects create white color in extremely thin layers, the researchers wished to investigate whether evolution optimized the wing scale morphology for white reflection with minimal material use, which they speculated it did. This hypothesis is difficult to prove, as this requires detailed knowledge of the scattering morphology combined with a suitable theoretical model.

The NCCR physicists used a method called cryoptychographic X-ray tomography to obtain a complete three-dimensional structural dataset of the network morphology within a white beetle wing scale. The method is a combination of computer modelling and X-ray nanotomography, which uses X-rays to create cross-sections from a 3D-object, to precisely understand the morphology of the beetle shell and its optical function.

White beetles are rare in nature.

To carry out the measurement, a tiny piece of beetle shell is glued to a platinum tip, which is then rotated around a central axis to ensure that the sample is scanned from all sides. This is then reconstructed into a virtual 3D model.

"This type of visualization helps us extract important parameters such as size and length statistics," says NCCR senior scientist Bodo Wilts. "With these results, we were able to understand what makes the beetle white."

By digitally manipulating this 3D representation, the researchers were able to demonstrate that this morphology provides the highest white retro-reflection while using the least material, in other words, the lightest possible scale with this capacity. Changing any of the network morphology parameters either led to a weight increase, thicker scales, or diminished capacity of the scale to reflect white light, indicating that evolution did indeed help optimize the beetle shell.

Applications such as thinner, lighter, paper or improved paint are obvious uses for any findings made by the NCCR researchers. Standard white paper is at least 20 to 100 times thicker than the beetle shell. Beetle-inspired paint could help reduce the amount needed to cover a wall to achieve the same opaque effect. However, there could be many more applications, according to Wilts.

"Materials that scatter light are needed wherever color plays a role," he points out. "Paint and paper are the easiest to grasp, but you might want to use this type of structure as a material in solar cells, for example, to improve their light absorption, or in displays."

Reference

Wilts, B.D.; Sheng, X.; Holler, M.; Diaz, A.; Guizar-Sicairos, M.; Raabe, J.; Hoppe, R.; Liu, S.-H.; Langford, R.; Onelli, O. D.; Chen, D.; Torquato, S.; Steiner, U.; Schroer, C. G.; Vignolini, S.; Sepe, A. Evolutionary-optimized photonic network structure in white beetle wing scales, Advanced Materials 2017, 1702057

Shear responsive

Force-induced permeability

NCCR Bio-Inspired Materials researchers are developing nanoscale polymer containers that react to mechanical forces, which could be useful for a variety of applications, such as drug-delivery, the release of fragrances, or 3D printing.

Materials that react to the application of mechanical forces are one of the NCCR Bio-Inspired Materials' focuses. Cell membranes are integral components of cells and organelles, and the existence of force-responsive membranes in nature shows that it is possible to create these types of membranes. The senses of touch and hearing, as well as the control of blood pressure are produced by efficient stress sensing systems in cell membranes.

Imitating nature is a complex task, however, since permeability changes are achieved through complex membrane proteins, and lipid membranes are fragile. The scientists, led by NCCR Principal Investigator Professor Nico Bruns at the Adolphe Merkle Institute, create biomimetic polymer membranes that are more stable than their natural counterparts and do not need pore-forming proteins for force-induced permeability changes, allowing the use of these membranes in more demanding environments and applications.

"To establish the concept of shear responsive polymer membranes, we are trying to mimic certain molecular processes that lead to stress or force-induced permeability changes in biomimetic polymer membranes," NCCR PhD student Omar Rifaie Graham explains.

The researchers were able to imitate this effect by producing a suspension of nanoscale-sized hollow containers called polymersomes. These have the advantage of being able to encapsulate water-soluble compounds. They can also hold larger molecules such as proteins or DNA, which are increasingly used for medical therapies.

To achieve this, the polymers that form the polymersomes were modified with chemical motifs that react to mechanical stress. This was made possible through a series of collaborations within the NCCR, but also with external researchers such as the Wenz group at the Saarland University in Germany.

"Collaborations are essential for this kind of research that spans polymer synthesis, polymer self-assembly, fluid dynamics, and various possible applications," says Bruns. "The NCCR offers the environment to push such interdisciplinary projects forward."

Besides synthesizing mechanophores, the researchers also developed new methods to quantitatively measure the effect of mechanical force

Our sense of touch is produced by efficient stress sensing systems in cell membranes.

on polymersomes in a solution. NCCR Principal Investigator Professor Marco Lattuada from the University of Fribourg provided the key findings that enabled the research team to understand the effects of the applied forces on the polymersomes. Lattuada was able to establish that the process that facilitates the activation of the polymersomes results from a reversible shape deformation of the nanocapsules in a turbulent flow.

> "We are trying to mimic certain molecular processes that lead to stress or force-induced permeability changes in biomimetic polymer membranes."
> Omar Rifaie Graham

"Force-responsive polymersome membranes are stable and do not disassemble," adds Bruns. "However, their permeability can be switched on in a turbulent flow, allowing for the controlled release of cargo from within the polymersomes."

This means that mechanical forces could be used for the triggered release of compounds from the polymer nanocapsules, which could be useful for drug-delivery, the release of fragrances, or 3D printing.

Further efforts will be required to determine the threshold forces needed to induce permeability in the polymersome membrane. Moreover, the force-responsive containers will be investigated as nanoreactors that mimic force-activated reaction compartments in living organisms.

Golden touch

Putting the squeeze on viruses

NCCR Bio-Inspired materials researchers at Lausanne's Federal Institute of Technology (EPFL) have developed gold nanoparticles that can capture and destroy viruses, opening the door to safer, more efficient, and potentially preventive anti-viral treatments, while helping to reduce the usage of antibiotics.

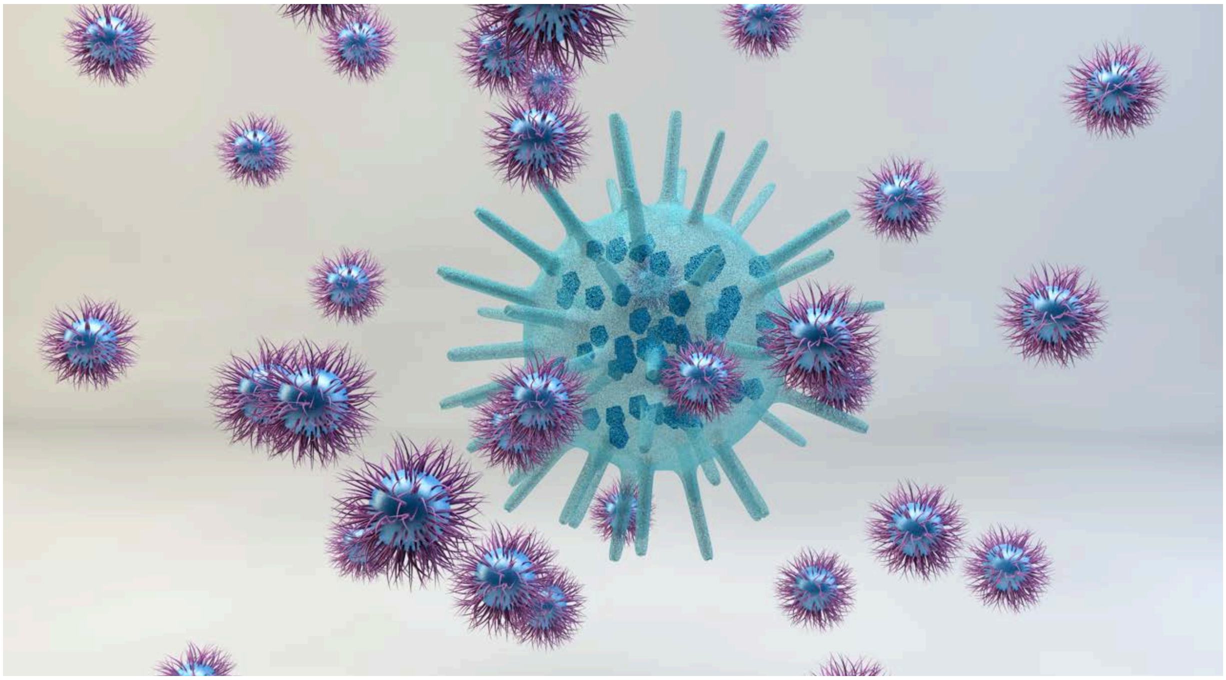
Millions of people die every year because of viral diseases. Some of these illnesses are well documented, for example, HIV/AIDS, Dengue fever, and diarrhoea. Others emerge with an ever increasing frequency, such as Ebola, Zika, and more recently, Chikungunya. This last disease killed more than ten people in Italy alone in September 2017. Perhaps a lesser known fact is that viral infections, even when non-lethal (such as flu-like respiratory infections), place a huge economic burden on health systems in developing countries.

The best, and most recommended, option to fight these infections is to use vaccines. However, these are not always widely available, do not exist for unknown viruses, and have no efficacy once a patient has been infected. The second line of defence is a battery of drugs. There are very effective pharmaceuticals on the market, but they are infection specific, targeting diseases such as HIV and hepatitis C. As a consequence, there is a dire need for broad-spectrum antivirals capable of fighting a wide variety of infections. Such antivirals would be the equivalent of broad-spectrum antibiotics, similar to penicillin, something most people have taken against an unknown bacterial infection. The goal now is to discover an equivalent for viral infections.

NCCR Bio-Inspired Materials Principal Investigator Professor Francesco Stellacci's laboratory has risen to the challenge, taking the first steps towards the development of such antivirals by creating gold nanoparticles (NPs) that mimic the cell-receptors that viral ligands seek. Inspired by nature, the researchers have designed NPs to be multivalent, in other words, to have multiple arms, so that, upon binding, they squeeze the target, eventually leading to the collapse of the virus' integrity, and rendering them ineffective. The result is a non-toxic, broad-spectrum – as it includes the most common target for viral ligands – and effective drug.

Stellacci and his team have demonstrated that this NP drug is effective in vivo in mice affected by Respiratory Syncytial Virus (RSV), which is the virus responsible for the lung infection that develops into pneumonia. It kills close to half a million people every year, and there is no effective drug, or vaccine, against it. Using a nasal spray containing ten micrograms of Stellacci's particles led to complete clearance of the virus from the mice's lungs.

The NP method could constitute a single response to fight the many viruses for which there is no available treatment, and which kill too many



A virus being swarmed by nanoparticles.

patients. A number of countries, especially developing nations, also do not have the appropriate means to make precise diagnoses, establishing a need for non-specific therapies.

Another potential advantage is that the gold nanoparticles could help slow human resistance to antibiotics. “Physicians often prescribe antibiotics when a patient is suffering from a viral infection, which is wrong since they only target bacterial infections,” says Stellacci. “This misuse leads to virus mutations, and antibiotic resistance in individuals.”

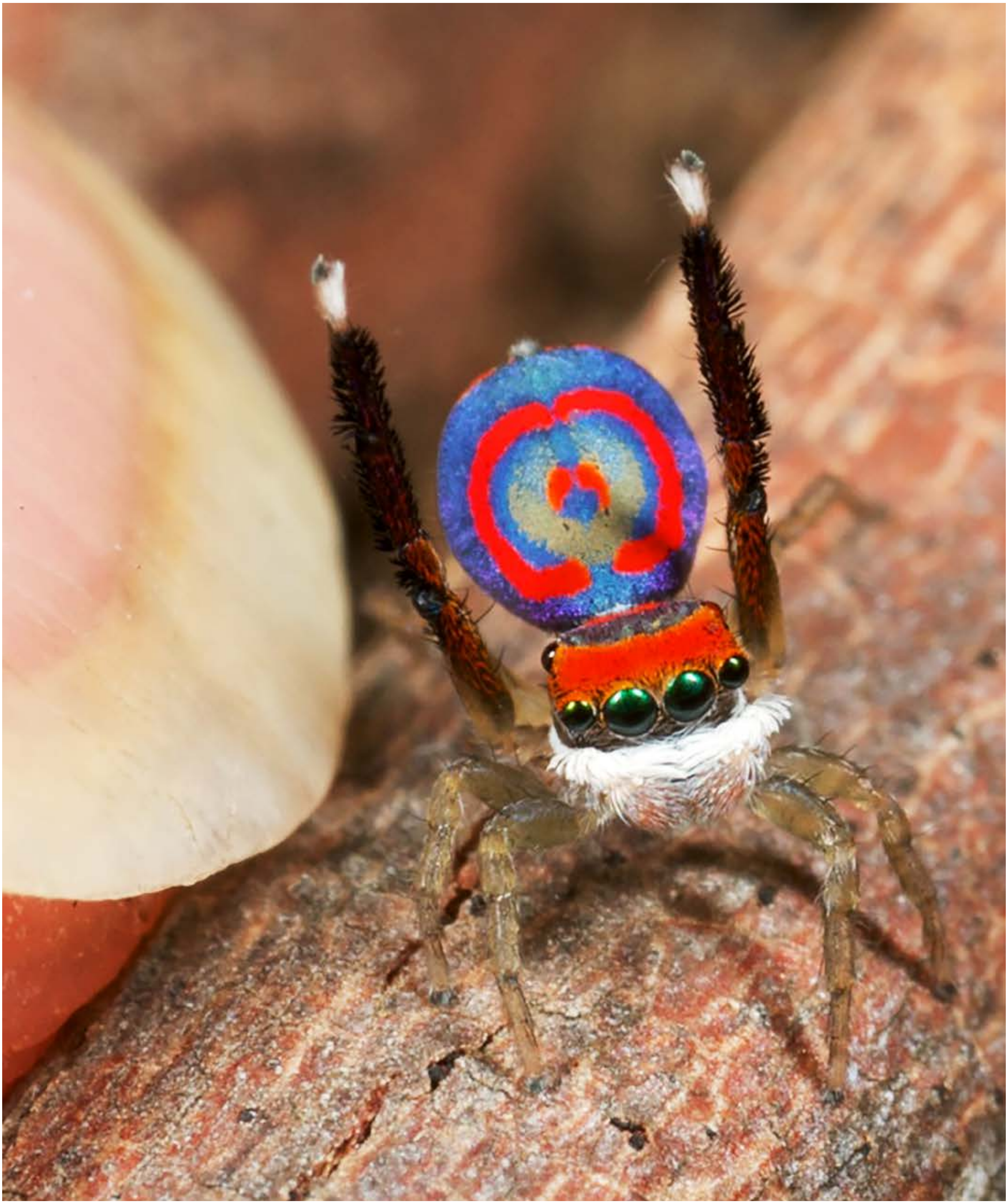
Using mechanical force to counter viruses also helps avoid the use of chemical substances. “Viruses use our cells to spread, so it is extremely difficult to find a chemical solution that destroys the virus while not affecting the cell,” Stellacci explains. “The chemical approach favored by researchers until now is toxic for human beings, even if it can destroy the target virus.” Because it is non-toxic, the mechanical approach might also provide another benefit, as it could be used preventively against viral infections, something that has been impossible thus far.

Besides RSV, further conclusive experiments were carried out in vitro on the herpes simplex virus, papillomaviruses (the most common cause of cervical cancer), lentiviruses (most notably responsible for HIV), and dengue, suggesting that gold nanoparticles could be used to combat a wide variety of viruses. According to Stellacci, the next steps are targeting other families of viruses, specifically influenza, and rendering the nanoparticles closer to common drugs to simplify their use.

This research was funded in part by a translational medicine research prize awarded by the Leenaards Foundation in 2016 to Stellacci and colleagues from the Geneva and Lausanne university hospitals.

Reference

Cagno, V.; Andreozzi, P.; D’Alicarnasso, M.; Silva, P.J.; Mueller, M.; Galloux, M.; Le Goffic, R.; Jones, S.T; Vallino, M.; Hodek, J.; Weber, J.; Sen, S.; Janeček, E.; Bekdemir, A.; Sanavio, B.; Martinelli, C.; Donalisio, M.; Rameix Welti, M.; Eleouet, J.F.; Han, Y.; Kaiser, L.; Vukovic, L.; Tapparel, C.; Král, P.; Krol, S.; Lembo, D.; Stellacci, F. Broad-spectrum non-toxic antiviral nanoparticles with a virucidal inhibition mechanism, Nature Materials, 2017.



NCCR researchers investigated the structural colors of the tiny Australian Maratur splendens spider.

98

Researchers

CHF 27.8 million

Funding Phase 1

Including CHF 12 million from the SNSF

27 Nationalities

Multinational

Spain, France, Germany, Belgium, Hungary, Croatia, USA, UK, Slovenia, Ukraine, India, Italy, Russia, Brazil, Ireland, Turkey, Iran, Indonesia, Nigeria, Australia, Serbia, Portugal, Bulgaria, Morocco, Luxemburg, Romania and Switzerland

Partners

University of Fribourg (home institution), Adolphe Merkle Institute, University of Geneva, Federal Institutes of Technology in Lausanne and Zurich

57

Publications

17 publications involving two or more NCCR groups

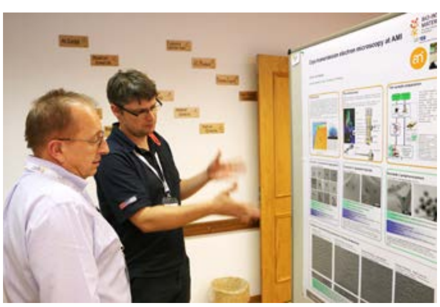
Note: All figures between March 1, 2016 and February 28, 2017

In brief

Annual Center Conference

The 2016 Annual Center Conference, held for the third time, took place in Charmey, near Fribourg.

The two keynote speakers came from the NCCR's External Advisory Board. Dr. Martin Michel of Nestlé's Food Science and Technology department in Lausanne provided insights into how an industrial research and development project could lead to a PhD. Professor Marek Urban of Clemson University (USA) gave a talk on encoding color, shape memory, and self-healing in polymers.



The annual conference provides many opportunities to discuss the latest NCCR research.

The other invited speaker was Professor Thomas Ward of the University of Basel and director of the NCCR Molecular Systems Engineering, who presented the activities of his center, which began operations approximately at the same time as the NCCR Bio-Inspired Materials.

Nobel Prize winner Professor Jean-Marie Lehn was the plenary speaker at TNT 2016.

TNT

The Trends in NanoTechnology conference was hosted by the NCCR Bio-Inspired Materials and the University of Fribourg for the first time in September 2016.

Organized by the Spanish Phantoms Foundation and chaired by NCCR Principal Investigator Professor Frank Scheffold of the university's physics department, the conference saw around 250 scientists gather to hear some of the latest developments in the field of bionanotechnology, applications of graphene or bio-inspired materials to cite but a few.

For many attendees, the highlight of the week was the plenary talk given by Professor Jean-Marie Lehn (University of Strasbourg), winner of the Nobel Prize in Chemistry in 1987. His well-attended presentation focused on adaptive functional materials and nanoarchitectures. Other highlights were talks by two Millennium Technology Prize winners, Michael Grätzel (EPFL) and Stuart Parkin (Max Planck Institute of Microstructure Physics).

Tenure

NCCR Principal Investigator and Swiss National Science Foundation Professor Marco Lattuada made the step up to a permanent position in 2016.

He assumed an associate professorship in the Department of Chemistry at the University of Fribourg, moving his group from the nearby Adolphe Merkle Institute.

Marco Lattuada's career has taken him from Italy to Fribourg, Switzerland via Zurich and the United States.

High end papers

Sagara, Y.; Kubo, K.; Nakamura, T.; Tamaoki, N.; Weder, C. Temperature-dependent mechanochromic behavior of mechanoresponsive luminescent compounds, Chem. Mater., 2016, 29, 1273.

Froufe-Pérez, L.S.; Engel, M.; Damasceno, P.F. ; Muller, N.; Haberko, J.; Glotzer, S.C.; Scheffold, F. Role of short-range order and hyperuniformity in the formation of band gaps in disordered photonic materials, Phys. Rev. Lett., 2016, 117, 053902.

Wilts, B.D.; Wijnen, B.; Leertouwer, H.L.; Steiner, U.; Stavenga, D.G. Extreme refractive index wing scale beads containing dense pterin pigments cause the bright colors of pierid butterflies, Adv. Opt. Mater., 2016, 5, 1600879.

Mottas, I.; Milosevic, A.; Petri-Fink, A.; Rothen-Rutishauser, B.; Bourquin, C. Rapid screening method to evaluate impact of nanoparticles on macrophages, Nanoscale, 2017, 9, 2492.

Priebe, M.; Widmer, J.; Suhartha Löwa, N.; Abram, S.L.; Mottas, I.; Woischnig, A.K.; Brunetto P.S.; Khanna, N.; Bourquin, C.; Fromm, K.M. Antimicrobial silver-filled silica nanorattles with low immunotoxicity in dendritic cells, Nanomedicine, 2016, 13, 11.

New Fellow

Professor Christoph Weder, director of the NCCR Bio-Inspired Materials and the Adolphe Merkle Institute, was named a Fellow of the Division of Polymer Chemistry of the American Chemical Society.

He was one of just four awardees and the only academic recognized in 2017. Nominations are based on demonstrated achievements in and contributions to polymer science and the profession. The number of new fellows chosen each year is equal to no more than 0.1% of the ACS polymer chemistry division's current membership.

Professor Weder was also named as an individual member of the Swiss Academy of Engineering Sciences (SATW). He was recognized for his pioneering work in the development of new nanomaterials that bridge fundamental research and practical applications, as well as for his contribution to the development of AMI.

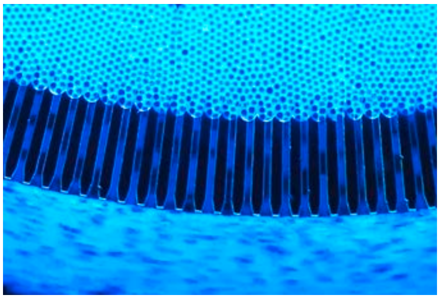
NCCR PI Christoph Weder was recognized for his work by US and Swiss associations.

Dr. Bodo Wilts spends much of his time investigating structural color.

Career boost

NCCR participant Bodo Wilts, senior scientist in the Steiner group at AMI, was awarded an Ambizione grant from the Swiss National Science Foundation that covers three years for his project "Smart Optical Materials Inspired by Nature."

He is currently investigating the optical and physical properties of nanostructured ordered and disordered materials. Inspiration for this work is found in the colors of bird feathers or butterfly wing scales. The project aims to understand the fundamentals of light-matter interactions with these structures and use these insights to manufacture novel optical materials.



Ofner's video showed the functioning micro-fluidic device he developed.

Imaging

A microencapsulation video loop created by PhD student Alessandro Ofner of the Studart group at ETHZ was distinguished in the SNSF 2017 Scientific Image Competition.

The competition encourages researchers in Switzerland to present their work to the public and the media. Photographs, images, and videos are rated in terms of their aesthetic quality and their ability to inspire and amaze, to convey or illustrate knowledge, to tell a story or to open new horizons.

Moving up

Dr. Samuel Jones of the Stellacci group at Lausanne's Federal Institute of Technology (EPFL), has moved to the University of Manchester to begin his independent career as a Dame Kathleen Ollerenshaw Fellow.

The NCCR alumnus's research group in Britain will focus on investigating virucidal material synthesis and development, pursuing the work he began in Switzerland.

Independence grant

Dr. Stephen Schrettl of the Weder group at the Adolphe Merkle Institute was the recipient of a grant from the NCCR.

Schrettl applied to obtain funding to purchase equipment that would allow him to perform small- and wide-angle X-ray scattering analyses at a controlled temperature. This equipment opens the way to study order-disorder transitions in metallo-supramolecular polymers. The NCCR Executive Board recognized the potential of this specialized equipment to foster Schrettl's career and to create synergies between Schrettl and other scattering specialists of the NCCR.

The Independence grant is designed to help talented young researchers in their pursuit of an independent academic career. It supports activities that go beyond their work as participants of the Center, such as travel to establish new contacts, preliminary experiments, writing of independent publications, and grant writing.

Dr. Stephen Schrettl is a group leader in the AMI Polymer Chemistry & Materials group.

Swiss NanoConvention

The NCCR and Adolphe Merkle Institute co-organized the 2017 Swiss NanoCovention in Fribourg on June 1 and 2.

One of the highlights was the special session on bio-inspired materials chaired by NCCR Principal Investigator Professor Nico Bruns, and another the podium discussion on nanomaterials in daily life, chaired by Professor Alke Fink.

NCCR staff members presented a number of research research projects, including electric eel-inspired power sources, mechanoresponsive drug delivery, and hazard assessment of graphene-based materials on human lung tissue.

NCCR PI Michael Mayer (Adolphe Merkle Institute) spoke about eel-inspired research.

Two of the three prizes for best poster at the conference went to the NCCR's Ilja Gunkel and Mirela Malekovic (both AMI Soft Matter Physics). The conference's local organizing committee, chaired by PI Professor Barbara Rothen-Rutishauser, included NCCR staff members (PI) Professor Fink, senior scientist Dimitri Vanhecke, Knowledge Transfer and Innovation Manager Eliav Haskal, as well as the administrative assistant Myriam Marano.

Dr. Khay Fong is investigating biological interactions of lipidic nanoparticles.

WINS

Dr. Khay Fong was the first recipient of the NCCR's Research Program for Women in Science Fellowship.

She joined the BioNanomaterials group at the Adolphe Merkle Institute early in 2017. Fong presented her project along with four other finalists at the Trends in NanoTechnology conference in Fribourg. The project will focus on the study of the potential biological interactions of lipidic nanoparticles used for drug delivery.

Her previous research experience includes investigating smart, stimuli-responsive nanomaterials that release drug molecules or imaging agents through a change in structure in the presence of specific enzymes.

Science slam

NCCR staff members Laura Neumann and Dimitri Vanhecke, both from the Adolphe Merkle Institute, finished in the top two positions of the University of Fribourg's 2017 German-language Science Slam competition.

Other NCCR staff were also involved in the event, with PhD student Frederik Neuhaus (Department of Chemistry, University of Fribourg) and Dr. Ilja Gunkel (Adolphe Merkle Institute) working as part of the organizing committee.

Laura Neumann's tale of broken hearts and self-healing materials was a winner.

Education

Mastering research

In 2016, in collaboration with the Adolphe Merkle Institute (AMI), the NCCR Bio-Inspired Materials launched a new master's program at the University of Fribourg aimed at students interested in the chemistry and physics of soft matter. The program's goal is to provide participants not only with a strong understanding of soft materials, but also with some experience working on an ongoing research project.

At the interface between physics, chemistry, biology, and materials science, the two-year program offers a unique interdisciplinary curriculum in the field of Soft Materials, sometimes also referred to as Soft Matter.

According to NCCR Education Delegate Professor Andreas Kilbinger, helping AMI launch the master's project was a logical step for the Center. "Fribourg has long been a center for soft matter and nanomaterials research, and has created a focus on bioinspired materials with our NCCR," he points out.

"Within the NCCR, we are aiming to creat training opportunities for a broad range of age and education levels. The soft materials master is where the focused expertise of our faculty gets passed on to the students of our university," he adds. "Naturally, this is an extremely important aspect of our university teaching and beneficial to both the master's students as well as the research groups who will be able to recruit well-trained PhD candidates."

Soft materials include polymers, colloids, foams, gels, and biological tissues, along with others that are part solid and part liquid and are often easily deformable. They are everywhere and many industries, including the traditional materials sector as well as the medical, pharmaceutical, and food industries, depend increasingly on professionals with specific training in this domain. The master's program therefore provides students with an excellent basis for employment in industry or to launch an academic career.

"They'll graduate as highly skilled individuals with strengthened language and communication skills, who are capable of conveying ideas and concepts and discussing projects on a very high scientific level," says NCCR Principal Investigator Professor Alke Fink, who oversees the program with her colleague, NCCR PI Professor Ullrich Steiner.

"Some of them will pursue doctoral studies after the program, when they will deepen their disciplinary and interdisciplinary expertise, and are prepared for leadership roles in industry and academia," she expands.

Soft matter science is by its very nature interdisciplinary, bridging not only chemistry, physics, and biology, but also materials science and engineering. The master's program itself aims to mir-

The master's students are called upon to actively participate in classes.

ror this interdisciplinarity. It consists of compulsory and elective courses along with small projects and the larger thesis research projects. These courses include varied topics, such as nanomaterials, microscopy and scattering techniques, soft matter and biophysics, polymer chemistry, and fundamental cell biology, but also science writing, ethics, and innovation.

The students are trained to conduct research in contemporary fields of materials chemistry and physics.

"Interdisciplinary research requires broad knowledge, motivation, and mutual respect. In order to understand and solve problems with roots in multiple disciplines, we will teach students how to integrate ideas," adds Fink. "Our goal is to help students develop an appreciation of the differences between disciplines on how to approach a problem."

What is crucial, though, is that their work is integrated into ongoing research projects.

"I think that it is important for students to be integrated into a real working environment and to be part of research team," Fink points out. "It is also important for them to feel that their work will have a real impact rather than just show they have mastered some techniques. Taking this approach will ensure that they consider a career as a working scientist as a worthwhile long-term objective."

This participation has multiple benefits for the master's students, such as learning the techniques related to the project and dealing with obstacles faced by a group's research.

"We teach how science works, make the students understand that everything doesn't always work out as anticipated, that ideas do not guarantee a working result," Fink explains. "There is also a sense of satisfaction when a project is successful, as it helps justify all the efforts made."

Hopefully, these efforts will start to pay off in 2018, when the first master's students will complete their program.

New horizons

Diverse experiences benefit PhD students

Earning a PhD does not only involve working in a laboratory for three or four years. Rather, it is also about gaining insights, building up a scientific profile, learning to innovate in research, and often also about experiencing a new culture.

The NCCR has set up a variety of programs and actions to help students improve these skills and widen their horizons.

The NCCR International Graduate Student Exchange (IGE) program allows NCCR doctoral students to spend up to three months in a laboratory abroad. Corine Reis of the Rüegg group at the University of Fribourg was one of the first to benefit from this program. She traveled to Hamburg to join the University Cancer Center and gain expertise in circulating tumor cells (CTCs), an experience she rates very positively.

“I learned things I wouldn’t have been able to in Fribourg,” she explains. “For example, I had access to CTCs that came directly from patients treated at the Hamburg University Hospital.” Reis says that initially, it was difficult working in a much larger laboratory than in Fribourg, but adds that the group she joined was “amazing,” and that the head of the laboratory was present and available to talk.

Céline Calvino is another student who recently headed abroad. Calvino, a member of the Weder group at the Adolphe Merkle Institute, travelled to join Professor Stuart Rowan’s laboratory at the University of Chicago. However, in her case, she feels it was less about learning about a new topic than it was about gaining an outside perspective.

“I wasn’t necessarily working on something different, but it shifted my viewpoint positively,” she points out. “The ways the work is organized are different, and it’s also a different environment culturally. It took me out of my comfort zone.”

Calvino believes it was a valuable experience on a personal level, and it also allowed her to establish some potential collaborations with researchers she met in Chicago. She says that her own PhD project was also boosted by her stay in the United States.

“I was able to make progress on my PhD,” she states. “I was able to take stock of my project, and I benefited from the feedback on my thesis.”

Host laboratories also get an opportunity to take a closer look at potential future recruits. The NCCR covers all of the costs associated with the students’ travel needs and residencies abroad.

So is it worth the time and energy to head abroad? “I would certainly recommend it to anyone,” says Calvino. “It has helped me think about my future, and I am certainly considering heading back to the United States for a postdoctoral research project.”

PhD students can travel as far away as cities such as Chicago.

For those considering a longer stay abroad, the NCCR also offers mobility grants that cover six to twelve months abroad to its PhD students and postdoctoral researchers.

Closer to home, PhD students are switching laboratories to acquire new skills. Depending on their projects, the students benefit from the internal exchange program set up by the NCCR. Typically, they get to spend between two and eight weeks in another NCCR laboratory. The aim is to gain insights into a different research culture, exchange ideas, and learn new techniques. For Michela di Giannantonio of the University of Fribourg's Fromm group, this meant joining the Weder group for a few months with the intent of combining polymer and organometallic chemistry.

"I had no idea about polymer chemistry, so it was an opportunity to learn new techniques," says di Giannantonio. She also sees the experience as a professional and personal enrichment. "It allows you to create new collaborations and work together to find innovative solutions," she points out.

Di Giannantonio's experience shows that you travelling far away is not necessarily required in order to learn something new. Regardless of distance, spending time in other laboratories allows students to gain new perspectives and prompts them to begin thinking seriously about their future.


kidsUni

KidsUni

Getting children interested in science

Outreach is one of the many activities undertaken by the NCCR Bio-Inspired Materials. The Center actively organizes and participates in initiatives aiming to awaken the interest of children and teenagers in science.

Specifically, the goal is to promote so-called MINT subjects (mathematics, information technology, natural sciences, and technology) and potential careers in these fields. The programs not only involve children and students, but also offer professional training for elementary school teachers. Ideally, these different approaches will result in planting a "seed of interest."

KidsUni at the University of Fribourg is one of these initiatives. This program, created in 2014 by staff from the university's Department of Chemistry, is partly funded by the NCCR. Today, professors, researchers, and doctoral students from the University of Fribourg's chemistry department, the Adolphe Merkle Institute, and Fribourg's University of Applied Sciences have joined the program, with the goal of explaining scientific concepts such as color, polymers, and soap to children with simple laboratory experiments that they can carry out themselves.

"Many kids are afraid of math and physics, so we need to get them interested early, before they assimilate stereotypes that will scare them away," says NCCR Principal Investigator Alke Fink, one of the founders of KidsUni. "But most of these kids are often much more capable than adults of grasping complex ideas."

Children are far more open to learning about science than most adults think.

This outreach activity is also beneficial for the researchers who participate. "I enjoy the contact with the children," explains Fink. "They are motivated, excited, and they don't come with preconceived ideas."

Fink also sees programs such as KidsUni as part of a more important mission.

"It's important that we go outside the university to get children, teenagers, and adults interested in science. Projects like KidsUni, which brings science to primary schoolchildren, or open days, can play an important role," says Fink. "In the current political climate, where science is being challenged – rightly or wrongly – we have to get our message out. But it is just as important to have a dialogue. We have to provide relatable information so there can be an exchange between both sides."

The KidsUni program has had no trouble attracting interest. Since its launch three years ago, the program has hosted approximately 100 children. Twice a year, ten or more children, aged 11 to 12, spend five afternoons learning some of the basics of science. "It is really popular, and word-of-mouth has helped spread our message" adds Fink.

Given the success so far, Fink would like to see it expand beyond chemistry to other disciplines covered by the NCCR. "I could see it taking in physics, medicine, and biology in the future for example," says Fink. "Ideally, we should also extend it to smaller children, between the ages of five and six, albeit in a slightly less intense format."

Fresh opportunities

Undergraduates get a taste of research with summer projects

Since 2015, the NCCR Bio-Inspired Materials has organized a summer undergraduate research program at the University of Fribourg. Each year, up to 20 students from abroad spend what would be their time off participating in cutting-edge science within one of the Center's groups.

With this first taste of advanced research work comes an opportunity to acquire hands-on work experience, but also to develop transferable skills and to network with professionals.

Students taking part in the program spend eight to twelve weeks between May and September working in one of the NCCR's laboratories, where they have the opportunity to work on a research project and to interact with leading experts in their fields of interest, as well as with fellow students from around the world.

"I applied for the program as I wanted to have some experience doing actual research, as well as being able to go to a different country," explains Olivia Morley of the University of Cambridge. "I managed to gain first-hand experience in a laboratory, learning skills in physics as well as analysis. This has helped me in my degree, and will serve also for later in life, when applying for jobs and PhDs."

This opinion is far from unique. When questioned about their reasons for participating in the program, the undergraduates all pointed to the possibility of having a research project to work on and learning something new.

"As an undergraduate student, I was able to take ownership of a project, and really gain experience I wouldn't have been able to get back in the United States," says Seth Meade of Cleveland's Case Western Reserve University.

His opinion is shared by Katerina Schwab from the University of British Columbia. "As an undergraduate, I felt that I learnt different lab techniques from my time in Switzerland that I would not have acquired at UBC, broadening my base of training."

The students, such as Kunal Rath, another undergraduate from Case Western Reserve University, also highlight the benefits of working in the laboratory over the summer.

"Hands-on use of machines and analysis techniques that I had learned about in classes was invaluable to furthering my understanding of my studies," says Rath. "I also learned a lot about the process of research, from establishing a theory to testing it."

For some, this process is almost as important as the laboratory work. "I gained an appreciation for scientific material and knowledge, as conducting my research would sometimes be a slow and tedious process, though very rewarding," explains Alexandra Sobisch of Cleveland's John Carroll University.

Participation in the program can also be a rewarding process for the PhD students and post-

The undergraduate students spend time outside of the laboratory as part of the social program organized for them.

doctoral researchers who mentor the undergraduates during their stay in Switzerland.

"When you are working on your own, on a variety of projects, it is difficult to advance strikingly on one," says PhD student Omar Rifaie Graham of the Adolphe Merkle Institute. "So in this regard, my student brought some very exciting data that I would have not been able to achieve by myself in such a short period of time."

Beyond doing research in the hosting laboratory, the program's students come together for scientific lectures as well as social and networking events. At the end of the summer, the students present the results of their research projects at a poster session. The students have the opportunity to learn about Switzerland from an insider perspective as well, and to take some first steps toward learning or practicing French and German.

Professor Andreas Kilbinger, the NCCR's Education Delegate, is not surprised by the students' impressions of their stay in Switzerland.

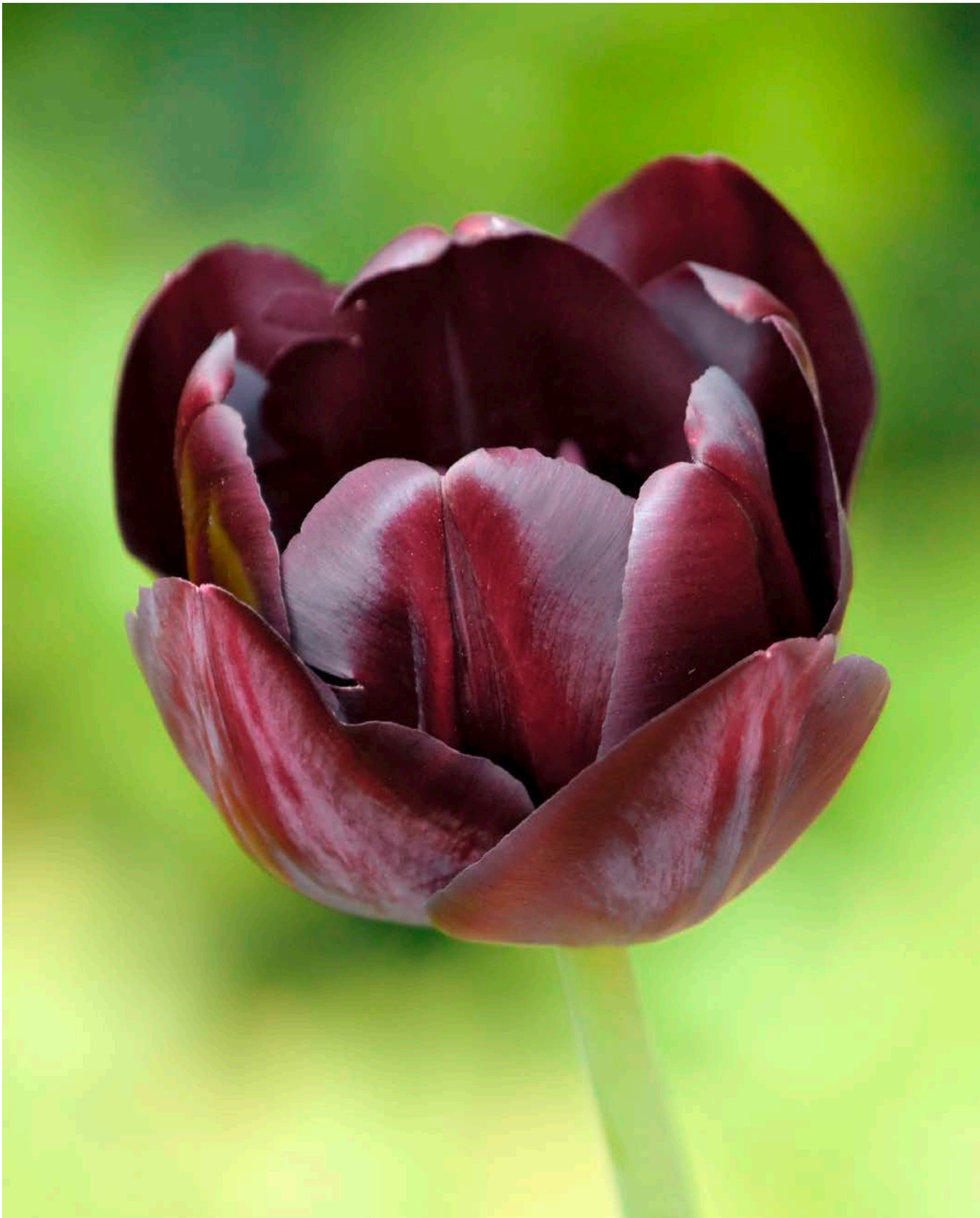
"The URI program is one of the great success stories of our NCCR," he says. "Hosting these motivated undergraduates from all around the world creates many new networking opportunities, not just for the undergraduates themselves, but also for the PIs, postdocs, and PhD students of our NCCR. In the mid to long term, I also expect our soft materials master and PhD recruiting to benefit from this program."

So will they come back? No guarantees, but the experience certainly makes students more receptive to living and working abroad.

"Travelling to Switzerland made me realize how easy it would be to study abroad – much more so than I previously would have thought," says Olivia Morley.

"I enjoyed working with people from a variety of backgrounds, all with different experiences and perspectives," adds Kunal. "I would be interested in pursuing my PhD in Switzerland or a different country."

Would they recommend the program? Certainly, according to Annabelle Davey of Case Western Reserve University. "I recommended it to someone and he ended up doing the program as well. I had a great summer working on an exciting project, I made friends that I am still in touch with, and I travelled to new places that I otherwise wouldn't have been able to visit."



PlaMatSu

From plants to innovative new materials

Bio-inspired research took another step forward at the NCCR in 2016 with the launch of the Innovative Training Network on Plant Inspired Materials and Surfaces (PlaMatSu).

Backed by CHF 2.6 million awarded by the European Commission's Marie Skłodowska-Curie Actions, the research consortium, coordinated by NCCR PI Professor Nico Bruns (Adolphe Merkle Institute), and bringing together scientists from the Universities of Fribourg (Switzerland), Freiburg (Germany), and Cambridge (UK), allows nine graduate students to carry out their PhD research on materials inspired by plants.

The objective is to allow the students to pursue their academic training within an international, multidisciplinary framework, along with temporary industrial secondments. The funding is also provided to encourage transnational and interdisciplinary mobility.

"It was an opportunity to intensify our links with the University of Freiburg and the University of Cambridge," says PlaMatSu coordinator Bruns. "It was also a chance to create a training and research network that complements the NCCR's bio-inspired research."

Linking the network's existence to the NCCR was vital in obtaining the European grant.

The Queen of the Night tulip is one plant being investigated by PlaMatSu researchers.

"The ITN would not have been possible without the NCCR, as it was clearly laid out in the proposal that the new network would integrate, complement, and strengthen the existing structures of the NCCR," adds Bruns. "All ITN students and PIs at the University of Fribourg are also members of the Center."

While participating in the PlaMatSu project, students benefit from direct access to multidisciplinary laboratories, working in the fields of soft matter physics, polymer chemistry, and plant biology, and having the opportunity to sharpen their research and development skills there. This means that PhD candidates will also leave their home institutions and travel regularly to the network's other laboratories as interns for a few weeks at a time.

"These are important opportunities, since they allow us to learn different techniques, and enjoy a different culture," explains PlaMatSu PhD student Johannes Bergmann.

Workshops also allow the students to develop their soft skills in ethics, technology transfer, management, writing, and communication. "Getting together for these workshops is also a chance to get to know the other PhD students better," adds Bergmann.

The NCCR also benefits from these workshops, according to Bruns. NCCR researchers take part in training events, as well as PlaMatSu's "Bio-inspired Materials" winter school. All ITN activities that take place in Switzerland are co-branded and co-hosted by the Center.

The research the ITN students are carrying out focuses on plant cuticles. This external layer, which protects plant leaves and petals, is made of bio-polymers and wax and has a hierarchical structure. It can, for example, regulate water permeability or lead to the development of colored, sticky, and smooth surfaces.

"Many researchers and engineers look at insects and mammals for bio-inspiration," Bruns explains. "Plants are underrepresented, except for some classical examples like the lotus effect, Velcro (plant burrs), and tree-like engineering in construction. The driving forces for our ITN were our contacts with the two botanists involved, who already have a long track record of bionic and bio-inspired research."

The researchers are investigating the formation and properties of cuticles in order to gain a fundamental genetic, developmental, and physical understanding of them, and to then exploit this knowledge to create artificial polymeric materials with advanced functionalities such as insect repellency, tunable friction properties, and color.

The first plants under the microscope are the Queen of the Night Tulip, the Hibiscus trionum (also known as the flower-of-the-hour), and the grapevine, with more to follow as the project progresses. The potential applications include natural colors for foods, optical materials, non-toxic insecticides, semipermeable membranes, and self-lubricating surfaces.

Given that the project is also a collaboration between academics and industry, partners BASF, Fischer, and Tillwich will offer internships to the PlaMatSu students. These companies, whose sizes range from a family-owned business to multinational corporations, are already involved in biomimetic research and development (R&D), or have bio-inspired products on the market. Each student will spend at least a month working in one of the companies' facilities.

"These are great training opportunities for the students, as they get exposed to an industrial [research and development] setting," adds Bruns. "For the participating professors, these are good contacts for possible future collaborations."

The internships are designed to complement the students' academic training and increase their employability. They will also experience immersion in the industrial world, come into contact with different schools of thought and innovation culture in companies, as well as learn to work under more regulated conditions than in academia.

The Association of German Engineers (VDI) and Wikimedia Switzerland have also been recruited for the PlaMatSu program. They will both provide specific training modules in biomimetic technology transfer, bionic engineering, and public outreach via web-based media.


"A GOOD POUR"
STATE OF ART:
falling / versatility / cost
→ FIT WALL / CUT
DESC:
- repellent coatings? / hydrophobic
- flexibility / completely elastic to
- starts from a flat surface
- any shape that allows...
- create a pipe
- multilayered
single
might lead to, fit any
one fold, overlap of the surface

NanoLockin

Improving detection and characterization of nanoparticles

Detecting and identifying nanoparticles in samples is often a challenge, especially when the particles are part of real-life environment. NCCR researchers are moving into the second phase of the development of a system that will allow more reliable detection and characterization of nanoparticles.

In the beginning, the NCCR scientists, based at the Adolphe Merkle Institute, were looking to improve the quality of nanoparticles used in a cancer therapy known as magnetic hyperthermia. This new type of treatment promises less pain and fewer side effects for patients than traditional therapies. The treatment involves injecting a tumor site with iron oxide nanoparticles, then heating the particles using an alternating magnetic field. If successful, the heat generated destroys the tumor.

However, the therapy, which is being tested in a number of European hospitals, has its pitfalls. To work efficiently, the dosage of nanoparticles must be exactly right and the particles must have consistent properties, which is never certain when working at the nanoscale. Even minor variations can diminish the likelihood of a positive outcome, and fiber optic systems used so far have suffered from reliability issues.

To overcome this, the NCCR researchers needed to find a way of characterizing the nanoparticles. In order to be able to visualize the reactions of particles heated by a magnetic coil, they chose lock-in thermography, an imaging technology originally developed for the quality control of aircraft parts, as the starting point for their project.

In collaboration with the Zurich University of Applied Sciences (ZHAW), they developed a method they named NanoLockin, which can precisely measure the distribution of the nanoparticles as well as the heat they generate.

This technology relies on applying an alternating magnetic field and infrared imaging to precisely measure the heat produced by the nanoparticles. The results are then evaluated using software developed especially for this system by the ZHAW.

There is also no contact between the measurement device and the sample, meaning nanoparticles can be observed in realistic environments, such as tissue samples. Therefore, by using the newly developed method, production and dosing of those nanoparticles can be optimized.

When nanoparticles are used for cancer therapy, for example, this would mean that the particle concentration can be optimized for its target. Consequently, this would also mean that the treatment would work faster, more successfully, and at a lower cost.

A first successful prototype was developed for the NanoLockin project.

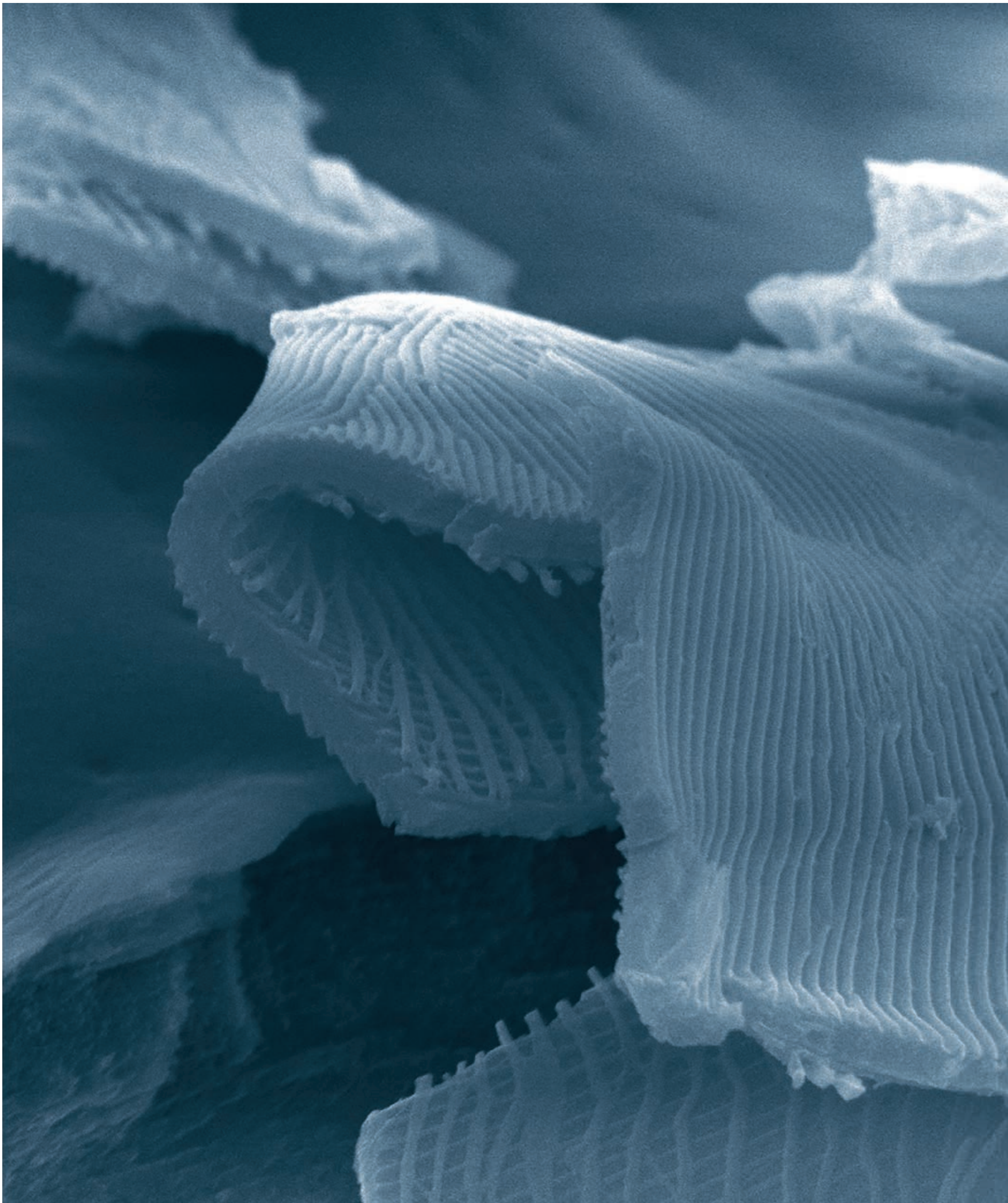
According to the NCCR researchers, this method of measurement has been validated. The team built two prototypes and established an initial business concept. They also managed to attract attention to their idea, particularly by placing third in the Ypsomed Innovation Fund's 2017 Innovation Award for research, development, and technology transfer.

However, the original system only works with magnetic nanoparticles, limiting its potential use. Further development is underway to increase the method's scope, moving away from the use of a magnetic coil to heating samples with a light source to stimulate a wider range of particles.

"This makes the method more adapted for the detection and analysis of nanoparticles in consumer products, for example," says project leader Christoph Geers. "This means we can carry out measurements in real-life liquid and solid environments."

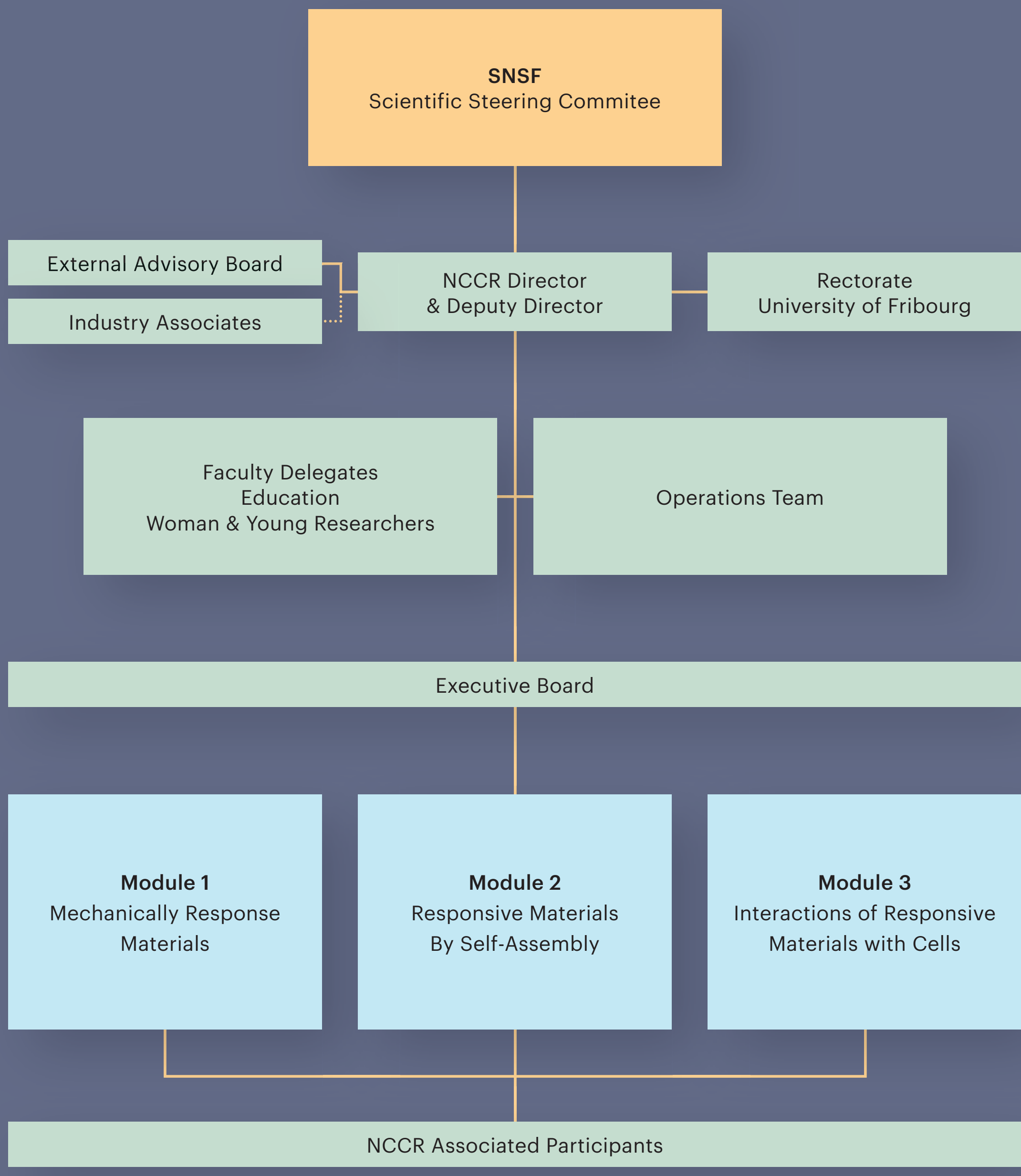
According to Geers, increasing the range of detection is as simple as switching the source of stimulation form heat to light, meaning the system is extremely flexible.

Now, the NanoLockin team hopes to continue building on its success. "In the next stages, we must focus on the market and develop potential customer contacts," Geers asserts. "With customer feedback, we can challenge our business idea and start to establish an even more solid business plan."



Scanning electron microscope image of a Maratus splendens spider scale.

Organization



The National Centers of Competence in Research (NCCR) are a research instrument of the Swiss National Science Foundation

Who is who

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Principal investigators

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  (Department of Physics, UniFR)
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  (Adolphe Merkle Institute, UniFR)
- Prof. Curzio Rüegg
  (Department of Medicine, UniFR)
- Prof. Frank Scheffold
  (Department of Physics, UniFR)
- Prof. Ullrich Steiner
  (Adolphe Merkle Institute, UniFR)
- Prof. Francesco Stellacci (
  Institute of Materials, EPFL)
- Prof. André Studart
  (Department of Materials, ETHZ)
- Prof. Christoph Weder
  (Adolphe Merkle Institute, UniFR)

Associate participants

- Prof. Aleksandra Radenovic (Institute of Bioengineering, EPFL)
- Prof. Andreas Zumbühl (Department of Chemistry, UniFR)

Management

- Dr. Ana Cordeiro, Scientific coordinator
- Scott Capper, Communications manager
- Dr. Cyrille Girardin, Grant writer
- Dr. Eliav Haskal, Knowledge Transfer and Innovation manager
- Myriam Marano, Administrative assistant

Research groups

Borkovec (UniGE)

- Prof. Michal Borkovec
- Dr. David Herman, Postdoctoral researcher
- Svilen Kozhuharov, Doctoral student
- Anne-Marie Loup, Secretary
- Dr. Plinio Maroni, Senior researcher
- Dr. Milad Radiom, Postdoctoral researcher
- Olivier Vassalli, Laboratory technician

Bourquin (UniGE)

- Prof. Carole Bourquin
- Aristea Massaras, Other staff
- Inès Mottas, Doctoral student
- Jérôme Widmer, Laboratory technician

Brader (UniFR)

- Prof. Joseph Brader
- Matthias Bott, Doctoral student

Bruns (AMI)

- Prof. Nico Bruns
- Livia Bast, Doctoral student
- Omar Rifaie Graham, Doctoral student
- Edward Apebende, Doctoral student

Fink/Rothen (AMI)

- Prof. Alke Fink
- Prof. Barbara Rothen-Rutishauser
- Liliane Ackermann Hirschi, Laboratory technician
- Pauline Blanc, Laboratory technician
- Dr. Mathias Bonmarin, Senior researcher
- David Burnand, Doctoral student
- Federica Crippa, Doctoral student
- Leopold Daum, Doctoral student
- Dr. Barbara Drasler, Postdoctoral researcher
- Daniel Hauser, Doctoral student
- Ana Milosevic, Doctoral student
- Dr. Laura Rodriguez-Lorenzo, Postdoctoral researcher

Fromm (UniFR)

- Prof. Katharina Fromm
- Sarah-Luise Abram, Doctoral student
- Michela Di Giannantonio, Doctoral student
- Dr. Nelly Hérault, Postdoctoral researcher
- Anja Holzheu, Doctoral student
- Dr. Lenke Horvath, Postdoctoral researcher
- Milene Tan, Doctoral student
- Serhii Vasylevskyi, Doctoral student
- Noémie Voutier, Doctoral student

Kilbinger (UniFR)

- Prof. Andreas Kilbinger
- Mahshid Alizadeh, Doctoral student
- Michael Badoux, Doctoral student
- Suzanne Drechsler, Doctoral student
- Phally Kong, Doctoral student
- Subhajit Pal, Doctoral student

Lattuada (UniFR)

- Prof. Marco Lattuada
- Golnaz Isapour Laskookalayeh, Doctoral student
- Dr. Julio Cesar Martinez Garcia, Postdoctoral researcher

Mayer (AMI)

- Prof. Michael Mayer
- Dr. Aziz Fennouri, Postdoctoral researcher

Radenovic (EPFL)

- Prof. Aleksandra Radenovic

Rüegg (UniFR)

- Prof. Curzio Rüegg
- Grégory Bieler, Support staff
- Corine Dos Santos Reis, Doctoral student
- Sarah Djahanbakhsh Rafiee, Doctoral student

Scheffold (UniFR)

- Prof. Frank Scheffold
- Marc Conley Gaurasundar, Doctoral student
- Dr. Luis Salvador Froufe–Pérez, Postdoctoral researcher
- Nathan Fuchs, Doctoral student
- Dr. Nesrin Senbil, Postdoctoral researcher
- Dr. Nicolas Muller, Postdoctoral researcher
- Dr. Veronique Trappe, Senior researcher

Steiner (AMI)

- Prof. Ullrich Steiner
- Mirela Malekovic, Doctoral student
- Dr. Bodo Wilts, Senior researcher

Stellacci (EPFL)

- Prof. Francesco Stellacci
- Özgün Kocabiyik, Doctoral student
- Dr. Samuel Jones, Senior researcher
- Emma-Rose Janecek, Postdoctoral researcher

Studart (ETHZ)

- Prof. André Studart
- Madeleine Grossmann, Doctoral student
- David Moore, Doctoral student
- Alessandro Ofner, Doctoral student
- Dr. Elena Tervoort, Postdoctoral researcher

Weder (AMI / UniFR)

- Prof. Christoph Weder
- Mathieu Ayer, Doctoral student
- Céline Calvino-Carneiro, Doctoral student
- Marc Karman, Doctoral student
- Anna Lavrenova, Doctoral student
- Laura Neumann, Doctoral student
- Dr. Stephen Schrettl, Postdoctoral researcher
- Dr. Maria Ester Verde Sesto, Postdoctoral researcher

Zumbühl (UniFR)

- Prof. Andreas Zumbühl
- Dennis Müller, Doctoral student
- Frederik Neuhaus, Doctoral student
- Etienne Stalder,Doctoral student
- Radu Tanasescu, Doctoral student

Support staff

- Dr. Sandor Balog, Senior researcher (AMI)
- Véronique Buclin, Laboratory technician (AMI)
- Dr. Aurélien Crochet, Senior researcher (UniFR)
- Laetitia Häni, Laboratory technician (AMI)
- RDr. Dimitri Vanhecke, Senior researcher (AMI)

Alumni

- Dr. Mathieu Ayer (Doctoral student, Weder group) 2014–2016
- Dr. Michael Badoux (Doctoral student, Kilbinger group) 2014–2016
- Dr. Cyrille Girardin (Management) 2014–2017
- Dr. Anna Lavrenova (Doctoral student, Weder group) 2014–2016
- Dr. Julio Cesar Martinez García (Postdoctoral researcher, Lattuada group) 2014–2016
- Dr. Nesrin Senbil (Postdoctoral researcher, Brader group) 2015–2016
- Milène Tan (Doctoral student, Fromm group) 2015–2016
- Dr. María Ester Verde Sesto (Postdoctoral researcher, Weder group) 2015–2016
- Arbnor Zenuni (Master student, Scheffold group) 2014–2016

Summer Students 2016

- Nicole Church (University of Cambridge)
- Charles Dean (University of Durham)
- William Gaffney (University of Durham)
- Zahra Gallagher (Virginia Polytechnic and State University)
- Sarah Grunsfeld (Massachusetts Institute of Technology)
- Christian Johansen (University of Cambridge)
- Zoé Kibbelaar (Harvard University)
- Ellen Kim (Dartmouth College)
- George Lewis (University of Durham)
- Olivia Morley (University of Cambridge)
- Mirae Parker (Stanford University)
- Sushila Ramani (University of Cambridge)
- Elis Roberts (University of Cambridge)
- Jan-Christian Schober (University of Hamburg)
- Katerina Schwab (University of British Columbia)
- Steven Seichepine (Virginia Polytechnic and State University)
- Hannah Thorne (University of Cambridge)
- Emma Vargo (Massachusetts Institute of Technology)
- Adam Weech (University of British Columbia)

External advisory board

- Prof. Helmut Coelfen, Department of Chemistry, University Konstanz, Germany
- Prof. Ursula Graf-Hausner, graf 3dcellculture, Switzerland
- Prof. Takashi Kato, Department of Chemistry and Biotechnology, University of Tokyo, Japan
- Prof. LaShanda Korley, Department of Macromolecular Science and Engineering, Case Western Reserve University, USA
- Dr. Christiane Löwe, Director Equal Opportunities Office, University of Zurich, Switzerland
- Dr. Martin Michel, Food Science and Technology Department, Nestlé Research Center, Switzerland
- Prof. Marcus Textor, Emeritus Professor, Department of Materials, ETH Zurich, Switzerland
- Prof. Marek Urban, Department of Materials Science and Engineering, Clemson University, USA

Abbreviations

AMI: Adolphe Merkle Institute;
UniFR: University of Fribourg;
UniGE: University of Geneva;
EPFL: Federal Institute of Technology Lausanne;
ETHZ: Federal Institute of Technology Zurich

Projects

Module 1: Mechanically responsive materials

1. Functional polymers though mechanochemistry
2. Probing force response of single macromolecules with atomic force microscopy
3. Self-assembled biomimetic nanostructures based on stimuli-responsive block copolymers
4. Polymers with molecular auxetic behavior
5. Mechanically tunable materials through stimuli-responsive capsules

Module 2: Responsive materials by self-assembly

6. Thermal response of polymeric building blocks for smart materials
7. Confinement induced stable liquid phases mimicking the behavior in cell membrane lipid bilayers
8. Ultrafast stimuli-responsive color-changing hydrogels
9. Multi-responsive photonic materials as tunable filters, sensors, and switches

AP1. Exploring vesicle-containing metallosupramolecular polymers (associated project)

AP1. Fluorescent nanodiamonds as quantum bio-molecular probes for live cell imaging and sensing (associated project)

Module 3: Interactions of responsive materials with cells

10. Sensoresponsive nanoelements to detect individual cancer cells
11. Evolving Nanoparticles
12. Magneto-responsive cell culture substrates that can be modulated in situ
13. Intelligent nanomaterials to reveal and to control their behavior in complex media, at the biointerface and in cells
14. Targeted cell killing by self-assembly of DNA- or RNA-triggered ion channels

Publications

Module 1

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Module 3

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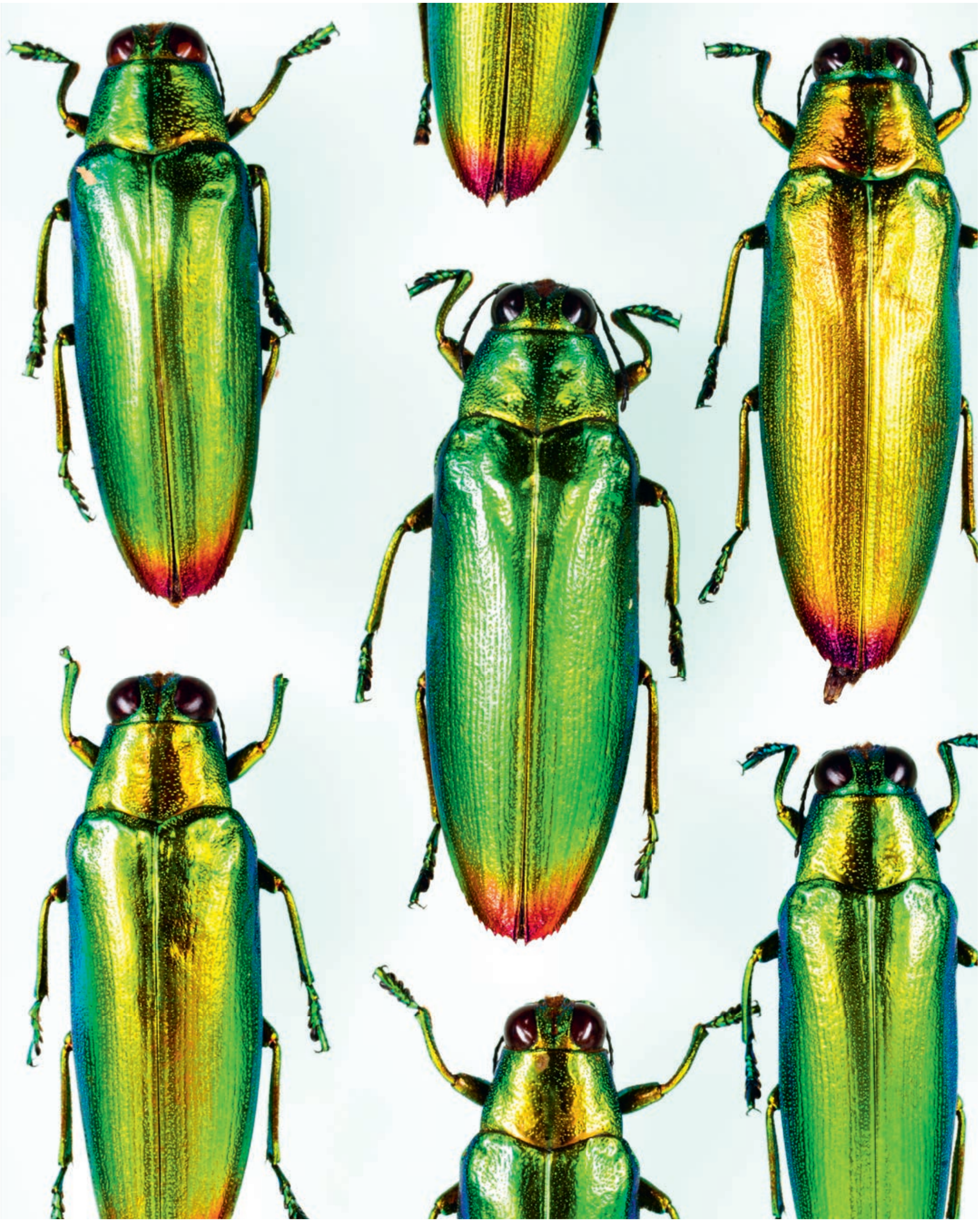


6

Industrial associates

Gender balance

More than half of the NCCR Ph.D. students are women (51%)

46% of the NCCR members are women

55 talks

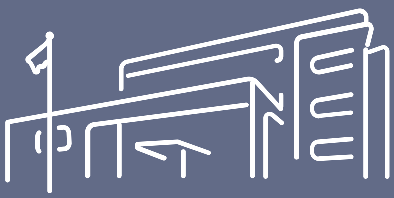
at conferences including 31 invited/keynotes

36

poster presentations

Headquarters

Adolphe Merkle Institute, University of Fribourg



11

NCCR seminars

Number of projects

15

including 2 associate projects

Note: All figures between March 1, 2016 and February 28, 2017

Seminars

The NCCR organizes seminars on a regular basis throughout the academic year. These seminars are both an excellent opportunity to learn about recent scientific advances from prominent researchers as well as a meeting point for NCCR participants to network and exchange ideas.

Speaker	Talk	Home Institution	Date
Dr. Christof Fattinger	Focal molography: the Coherent Detection of Biomolecular Interactions	Roche Innovation Center, F. Hoffmann-La Roche Ltd., Basel, Switzerland	10 March 2016
Prof. Laura Hartmann	Making sequence-controlled glycopolymers for biomedical applications	Heinrich Heine University Düsseldorf, Germany	12 April 2016
Dr. Marco Cantoni	State of the art of FIB nanotomography and FIB applications	Interdisciplinary Centre for Electron Microscopy (CIME), EPFL, Lausanne	11 May 2016
Prof. Jens Gobrecht	Synchrotron-based EUV radiation for nanolithography and actinic mask inspection	Laboratory for Micro- and Nanotechnology, Paul Scherrer Institut, Villigen	11 May 2016
Prof. Günter Reiter	Non-equilibrium properties of polymers in thin films	University of Freiburg, Germany	28 June 2016
Prof. Ivan Huc	Designing foldamers with predictable structures and dynamics	Institut Européen de Chimie et Biologie, Bordeaux University, France	16 August 2016
Prof. Molly M. Stevens	Designing materials for regenerative medicine and ultrasensitive biosensing	Imperial College London, UK	27 September 2016
Prof. Timo L.M. Ten Hagen	Nanoparticle-mediated drug delivery to treat cancer	Erasmus Medical Center, Rotterdam, The Netherlands	28 September 2016
Prof. Erika Eiser	DNA Driven Colloidal Aggregation at a Liquid-Liquid Interface	University of Cambridge, UK	13 December 2016
Prof. Dr. Volker Mailänder	Interaction of Nanoparticles with Proteins: the Miracle of the Stealth Effect	Center for Translational Nanomedicine, Universitätsmedizin der Johannes-Gutenberg Universität Mainz, Germany	20 December 2016
Dr. Frederik Wurm	Living polymerization to phosphorus-based or sequenced polymers	Max Planck Institute for Polymer Research Mainz, Germany	21 February 2017
Dr. Daniel Kümin	An Introduction to Biological Safety: What Does It Mean to Work in a Biological / Medical Laboratory. Joint seminar with the Adolphe Merkle Institute and the Department of Medicine, University of Fribourg	Institute of Virology und Immunology IVI, Biosafety & Engineering, Mittelhäusern, Switzerland	05 April 2017
Prof. Thomas Scheibel	Engineering, processing and applications of structural proteins: The tale of spider silk Adolphe Merkle Institute joint seminar	University of Bayreuth, Germany	09 May 2017

Impressum

Editorial: Christoph Weder / Curzio Rüegg / Lucas Montero / Scott Capper **Text:** Scott Capper **Proofreading:** Annika Weder **Photos:** Pages 2, 40, Bodo Wilts / Page 4, Charles Ellena / Pages 6, 15, Charly Rappo / Page 9, Ana Milosevic / Pages 11, 24, Alessandro Ofner / Pages 13, 17, 29, 34, Shutterstock / Page 19, SUNMIL/EPFL / Page 20, Jurgen Otto / Pages 22, 23, 39, 52, BM PHOTOS / Page 25, Ted Byrne / Page 25, Aldo Ellena / Page 33, NCCR Bio-Inspired Materials / Page 47, Nathan Fuchs / all other pictures, Scott Capper **Graphic design:** Grafikraum, Manuel Haefliger, Bern **Printer:** Imprimerie Saint-Paul, Fribourg

BIO-INSPIRED MATERIALS
NATIONAL CENTER OF COMPETENCE IN RESEARCH

NCCR Bio-Inspired Materials
c/o Adolphe Merkle Institute
Ch. des Verdiers 4
1700 Fribourg
Switzerland

Telephone +41 26 300 92 66
E-mail: info@bioinspired-materials.ch
bioinspired-materials.ch

FNSNF
Swiss National Science Foundation

The National Centers of Competence in Research (NCCR) are a research instrument of the Swiss National Science Foundation.

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