Activities report 2017–2018

National Center of Competence in Research Bio-Inspired Materials

FNSNF
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 to use the generated knowledge to develop innovative applications, particularly in the biomedical field.

Our research is organized in three modules that focus on *mechanically responsive materials, bio-inspired assembly of (optical) materials* and *responsive bio-interfaces and surfaces.* Each of these modules tackles major unsolved problems, provides opportunities for great scientific advances on its own, 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.

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Message from the directors

Dear readers

The NCCR Bio-Inspired Materials recently completed its initial four years of activity, and the Swiss National Science Foundation (SNSF) research council has approved funding for the second phase. This transition was an excellent opportunity to take stock, consolidate the research activities and other programs, and to plan for the next period.

Bringing together a large number of scientists from different domains to shape an ambitious, interdisciplinary, multi-site project around one common theme is a major challenge, and a good start is often key to future success. In our opinion, the Center could not have had a better start! In the first phase, it grew from 13 to 18 research groups at four sites (University of Fribourg, University of Geneva, and the Federal Institutes of Technology in Zurich and Lausanne), from which a total of 169 researchers (43% women) participated. Among this community's achievements: 170 papers were published; 127 oral presentations were given; five patents were filed; one spinoff company and three third-party funded entrepreneurial startups were created; and, the CHF 12 million grant awarded by the SNSF for Phase I was more than doubled by institutional matching funds and additional third-party funding.

Besides research, the educational activities of this NCCR were also highly prosperous. They included the launch of a new master's program in soft materials, a summer internship program, and numerous outreach activities for children. Our equal opportunities activities were praised by SNSF reviewers for their excellence and highlighted as an example for other NCCRs to follow.

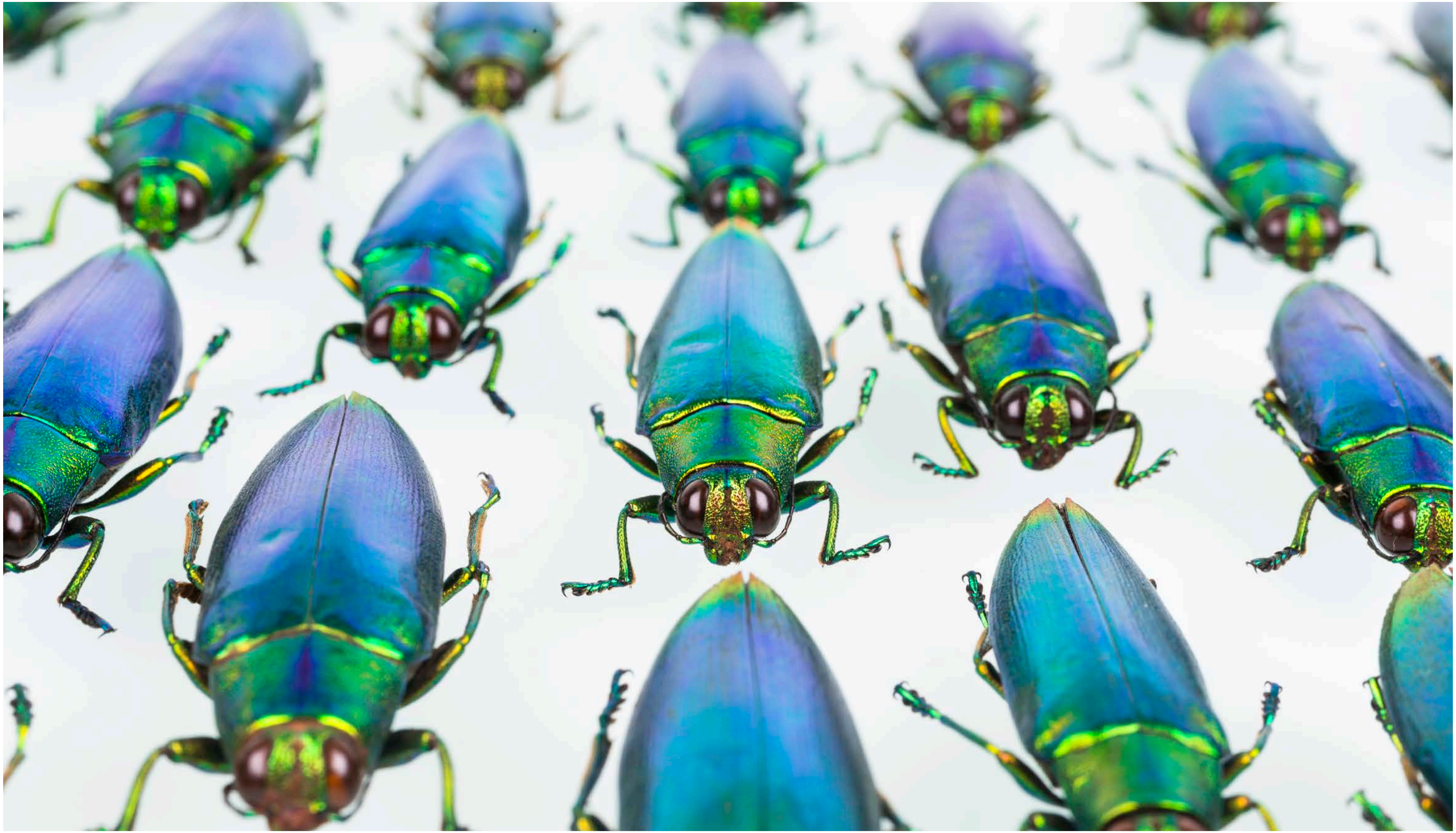
Not all of the successful outcomes can therefore be translated into hard numbers, as the realization of such a program also depends on "soft" factors, including social interactions, a sense of belonging, career development opportunities, and the perception by the international research community. Just as importantly, by launching and supporting actions and programs that integrate life and material sciences, the Center is helping the University of Fribourg, the NCCR's home institution, to achieve important strategic goals.

In the second phase, the overall structure of the program will be maintained, but it will be adjusted to reflect recommendations from the SNSF reviewers and the evolution of the research. The three existing Research Modules were refocused to promote internal synergies and cross-collaborations toward specific application fields. Six new project leaders have joined us for Phase II, bringing exciting initiatives with them. A new, large-scale project is under discussion, in which researchers would investigate the dynamics of interacting cell-material systems in a microfluidics platform based on systems developed in the Center.

As always, in this report, we have selected topics that are representative of the diverse activities in the different research modules and the overarching goal of the program. You will also find information on educational and technological aspects with promise for innovation and translation toward commercial developments.

On behalf of the whole NCCR Bio-Inspired Materials community, we hope that you will enjoy reading this report and that it will inspire you to learn more about our work and programs.

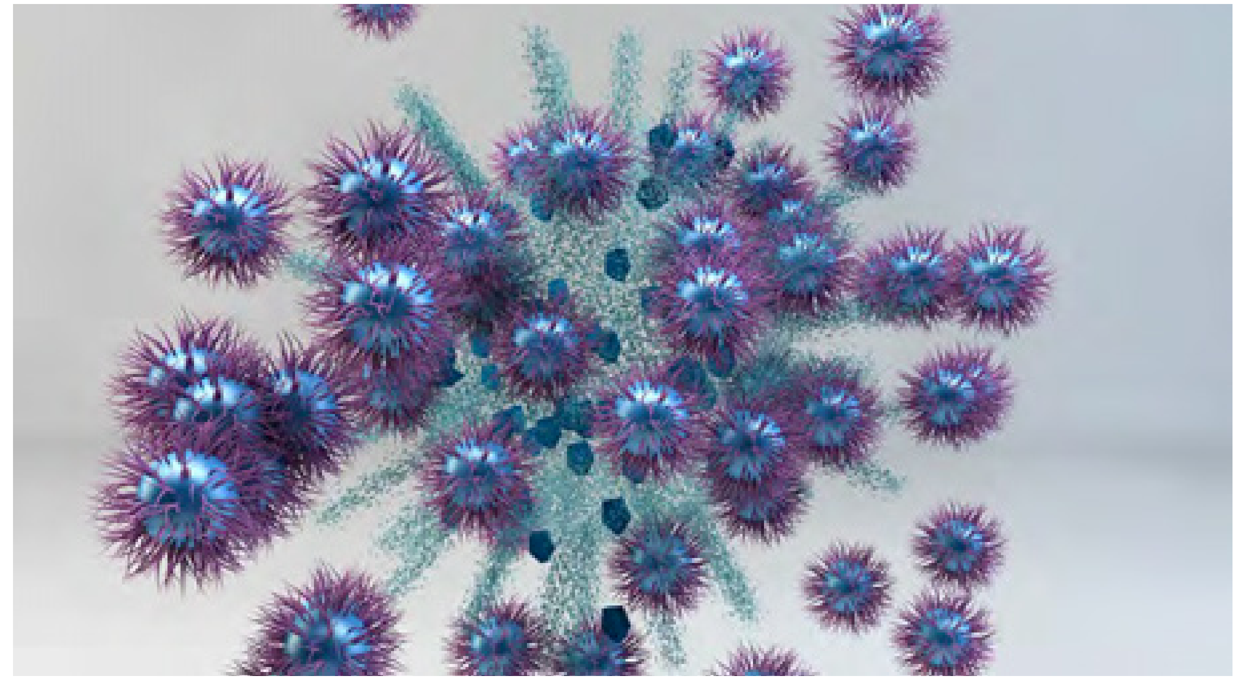
Christoph Weder & Curzio Rüegg
Directors NCCR Bio-Inspired Materials



Phase change

NCCR Bio-Inspired Materials enters phase transition

Having completed the first and started the second of presumably three four-year periods, the National Center of Competence in Research Bio-Inspired Materials is currently undergoing a phase transition. The projects originally planned have mostly been completed, and the first cohort of PhD students is graduating. At the same time, new research teams have joined the Center and fresh initiatives are being launched.



NCCR researchers have demonstrated how nanoparticles could inhibit viral infections.

"Intelligent" materials whose properties change in a selective and predictable manner in response to external stimuli such as chemicals, heat, light, mechanical force, or upon interaction with biological molecules or cells, are of fundamental scientific interest and potentially useful in countless applications. Many intriguing stimuli-responsive materials have already been developed, but their design and function are crude in comparison to their structurally complex, highly specific, and often multifunctional counterparts found in living organisms. To close this gap, scientists began using design principles found in nature as inspiration for the design of artificial materials with stimuli-responsive properties. Recognizing that the innovation potential in this domain is enormous, and that a large-scale interdisciplinary effort is required to achieve paradigm-changing scientific breakthroughs, the NCCR Bio-inspired Materials was launched in June 2014 with the vision of becoming an internationally recognized hub for research, education, and innovation in the domain of stimuli-responsive bio-inspired materials.

In Phase I, the Center's research activities focused on three major areas: mechanically responsive materials, responsive (optical) materials made by self-assembly, and interactions of responsive materials with living cells.

Inspired by mechanically responsive biological materials in nature that translate mechanical forces into chemical, electrical, or optical signals, NCCR researchers are mimicking such behavior in synthetic materials. In the quest to discover new mechanophores – mechanically responsive motifs that can be integrated into polymers and bestow them with useful functions – scientists showed that the integration of certain metal-ligand complexes can confer polymers with mechanoresponsive luminescence behavior, that is, a mechanically triggered fluorescence change, which is useful for force- and damage-sensing materials. It was shown that the mechanoresponsiveness of such materials can be tailored via the choice of the metal-ligand motif, and that in certain cases metal ions can be mechanically released. This effect is of interest for medical applications, for example to create antibacterial materials whose function is only activated when an implant is put under mechanical load, as well as for the catalysis of organic reactions. NCCR researchers introduced several other mechanophores, including sophisticated mechanically interlocked molecules known as rotaxanes, which can be activated by a much lower force and with a much higher selectivity than any other mechanophore.

Targeting auxetic polymers that, like cow teats, exhibit the strange phenomenon of expanding when being stretched, a new polymer that re-orients parts of its structure upon deformation was developed. Using single molecule force spectroscopy, it was shown that conformational transitions of carbon-carbon double bonds in a polymer backbone can be induced by mechanical force. This technique also proved to be a powerful tool for elucidating the mechanoresponse of polymers containing the above-mentioned mechanophores. An in-depth single-molecule force spectroscopy study of conventional polymers further revealed that force-extension profiles can be described by a modified freely jointed chain model and that a correlation with parameters that describe the conformation of polymer molecules in solution can be observed.

Remarkable progress was also made towards various types of mechanically responsive containers. Silver-loaded silica, titania, and cerium oxide nanocontainers were demonstrated to display a tunable release of antimicrobial silver ions, while biocompatibility was maintained. The nanocontainers were embedded in an oxide surface coating on implants and their mechanosensitive response in polymers is being tested. NCCR researchers also created force-responsive polymer nanocontainers, which can be opened upon shearing and thus release their content upon mechanical activation. This mechanism was exploited to mimic the phenomenon known as marine glow shown by the algae *Pyrocystis sp.*, which produce blue bioluminescence when mechanically disturbed by waves, ships, or swimming animals. The triggered release of compounds from the polymer nanocapsules could be useful for drug delivery, the release of fragrances, or 3D printing. To efficiently produce polymeric containers, parallelized microfluidic glass devices were developed that

The structure of white beetle shells could inspire more efficient solar cell systems.

allow the preparation of large quantities of microcapsules with tunable shell compositions.

Significant efforts were also devoted to the study and application of self-assembly processes to create hierarchical structures made from natural and synthetic materials. Exploiting properties on a hierarchy of length scales is a common concept nature uses to design materials with exceptional properties. In terms of material properties, the activities were directed towards photonics, which nature uses in various forms, such as for camouflage or signaling. Addressing fundamental questions on the assembly of soft particles, NCCR researchers were able to monitor the packing mechanism of stimuli responsive fuzzy microgels and provided original experimental support for a unified scenario describing the glass jamming transition in nano-emulsions. This work utilized cutting-edge light scattering and super-resolution microscopy techniques that allowed unprecedented insight into the local dynamics and structure of crowded suspensions of soft particles. Important technical progress has also been made concerning the correlation of the photonic properties of certain biological materials and their mesoscale structure. In a study published in *Nature*, NCCR researchers reported their discoveries on how structural colors in flowers are recognized by bees, while in another study the question of how some beetles have optimized the production of a rare white shell was answered. The team further characterized the enhanced refractive index scattering in butterflies and the chiral optics of self-assembled cellulose nanocrystals. Finally, disordered dielectric materials with structural correlations with unconventional optical behavior (i.e. transparent to long-wavelength radiation while having isotropic band gaps in another frequency range) were investigated and the behavior was explained.

Further, materials that mimic the color-changing behavior of chromatophores in octopuses were investigated. The function of the latter relies on the pigment displacement due to the expansion and contraction of a container. The new mimics consist of polymer-based microcapsules filled with water and magnetic nanoparticles, and change their color in response to magnetic-field-induced displacement of the nanoparticles.

Although stimuli-responsive, “smart” nanoparticles (NPs) promise important breakthroughs in disease diagnosis and therapy, translational progress in this domain has been slow, which can be attributed to many factors, including robustness of the materials and the lack of an understanding of the underlying fundamental biological interactions. With diagnostic applications in mind, NCCR teams focused their research on this latter aspect. Several groups collaborated on the optimization of polyethylene glycol (PEG) and lipoic-acid-functionalized gold NPs, which were shown to be 100 times more efficient than free antibodies in targeting breast cancer cells in vitro. The feasibility of a bio-inspired signal amplification cascade was demonstrated by cell-bound NPs carrying pro-coagulant enzymatic activity and the induction of cell-associated clotting. Further, conditions were established to optimize dense brush PEG conformation on gold NPs, which is relevant for enhancing the circulation time of systemically administered NPs. Another goal was to target and neutralize viruses by applying virucidal mechansims. This was achieved by designing gold NPs coated with mercaptoundecanesulfonate (MUS) ligands. A first breakthrough was the demonstration that this approach allows the irreversible inhibition of wild-type viruses such as Herpes Simplex, Human Papilloma, and Lentivirus viruses ex-vivo and in-vivo. It was also shown that MUS-modified cyclodextrin displays extensive virucidal activity, and that NPs modified with a specific glycan sequence can counter sialic acid-dependent viruses, including the influenza virus H1N1, at very low concentrations. These results demonstrate that bio-inspired viral mimicry can be exploited to achieve relevant virucidal activity and may have a significant societal impact.

In another project, the impact of surface functionalization protocols on the magnetic and thermal properties of superparamagnetic iron oxide nanoparticles (SPIONs) was investigated and a new technique for quantifying heat generated by SPIONs was established. These discoveries have great potential for scientific and commercial applications in the field of cell biology and cancer diagnostics. Furthermore, a biocompatible magneto-responsive substrate for cell cultures was developed, and the viscoelasticity of a soft polymer blend in air and liquid was characterized using a dynamic AFM technique.

Another important advance was the demonstration that NP endocytosis is cell and particle-type dependent, and that the endocytotic uptake pathways can be modulated by specifically tailored NPs. An analytical toolbox was developed to determine the colloidal stability of NPs in a biological environment, which is relevant for the design of safe and efficient nanoparticle formulations. A new project focuses on the programmed assembly of pore-forming peptides with predetermined pore diameters. The team demonstrated the proof-of-concept to modify the transmembrane part of a pore-forming peptide without compromising its insertion in lipid membranes. The addition of cholesterol moieties to DNA-modified peptides was shown to lead to a 20-fold increased potency of pore formation. It was further observed that conjugation of the transmembrane part of the peptide with a short hydrophilic DNA strand significantly increases the stability of the pores. Finally, a rapid screening method for assessing interaction of NPs with immune cells was developed with a significant impact on accelerating the development of nanomaterials for biomedical applications. This test received extensive coverage in the press and several awards at scientific conferences.

Overall, the research output of the Center – the integration of research efforts across the many research groups and various disciplines – has progressed beyond expectations. The emerging web of joint publications across projects, modules, and universities strikingly reflects that the Center creates and exploits significant synergies between groups and enables outcomes that would not be possible by funding individual research projects. For instance, the synthetic groups are sharing knowledge, chemical building blocks, and analytic methods to create and investigate mechanically responsive polymers. The Center has also capitalized on the complementary competences of the molecule-making groups and the single-molecule measurement techniques, as well as the processing capabilities of other teams, whereas the biomedical research is an integrated effort between

Bioluminescent algae have led to nanocontainers that can be opened by shear forces.

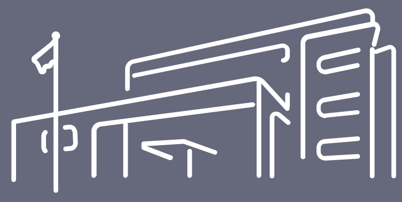
chemists, biologists, and medical doctors who investigate and utilize NPs.

Based on the very successful research outcomes in this initial phase of the NCCR, the research lines that were established will largely be continued in Phase II. The Center's activities on mechanically responsive materials will now specifically address the element of considering different length scales, efforts on biologically-inspired assembly will be concentrated on optical materials, and biological work will focus on responsive bio-interfaces and surfaces. The knowledge generated in Phase I will be used to create materials with specific functions, and as the research progresses, efforts will increasingly be directed towards specific application fields. The Center has launched Phase II with 20 research projects, which represents a significant growth vis-à-vis the 13 projects at the start of Phase I. If funding permits, a new effort to create complex cell models on a chip will be launched. This venture will serve to establish the next generation of organs on a chip, opening a pathway to induce and study cellular responses using a wide range of sensing and delivery systems. This high-risk/high-gain activity expands and integrates the existing research lines, focuses on a specific complex problem, and exploits the unique constellation of an existing center that unites researchers who have complementary expertise and an established track record of successful collaboration.

35
Seminars
by NCCR researchers

CHF 1.9 million
of external funding for translational projects, including 5 CTI and 2 BRIDGE grants

Headquarters
Adolphe Merkle Institute, University of Fribourg



18
Research groups
(including 2 associate groups)

20
equal opportunities round tables

7
industrial associates

5
NCCR alumni awarded Professorships abroad

46
undergraduate students
hosted within the NCCR's Summer Internships

Note: All figures between June 1, 2014, and February 28, 2018

Blue halo

Nanostructure guides bees to flowers

NCCR Bio-Inspired Materials Principal Investigator Professor Ullrich Steiner at the Adolphe Merkle Institute and colleagues at the University of Cambridge and London's Kew Royal Botanical Gardens have demonstrated that many types of flowers produce a so-called "halo" – a blue shine that allows bees to identify them more easily. This color is produced by the nanostructure of a flower's petals, which scatters light in the blue to ultraviolet range of the electromagnetic spectrum.

The blue halo increases a flower's visibility to pollinators.

Electron microscopy imaging shows that on a flower petal's surface, tiny ridges and grooves line up next to each other like a packet of dry spaghetti. When analyzing petals from different species, the researchers discovered that the structures vary greatly in height, width, and spacing. In fact, they learned that even on a single petal, these light-manipulating structures are surprisingly irregular, a phenomenon that physicists describe as "disorder," suggesting that different flowers should have different optical properties. Despite this, the flowers all produce a similar visual effect in the blue-to-ultraviolet wavelength region of the spectrum – the "blue halo effect". The scientists concluded that these messily ordered petal nanostructures likely evolved independently many times across flowering plants, but all reached the same luminous outcome that increases visibility to pollinators – an example of what is known as convergent evolution.

All flowering plants belong to the angiosperm lineage. Researchers analyzed some of the earliest diverging plants from this group and found no halo-producing petal ridges. They did, however, find several examples of halo-producing petals among the two major flower groups that emerged during the Cretaceous period over 100 million years ago: monocots and eudicots. The appearance of these coincided with the early evolution of flower-visiting insects, in particular nectar-sucking bees, suggesting that this optical signal targets pollinators and evolved many times across different flower lineages. Species that the team found to have halo-producing petals included *Oenothera stricta* (a type of Evening Primrose), *Ursinia speciosa* (a member of the daisy family) and *Hibiscus trionum* (known as the "Flower-of-the-hour"). All of the analyzed flowers revealed significant levels of apparent disorder in the dimensions and spacing of their petal nanostructures.

While previous studies have shown that many bee species have an innate preference for colors in the violet-blue range, plants do not always have the means to produce blue pigments.

"Many flowers lack the genetic and biochemical capability to manipulate pigment chemistry in the blue to ultraviolet spectrum," says Steiner. "The presence of these disordered photonic structures on their petals provides an alternative way to produce signals that attract insects."

By manufacturing artificial surfaces that replicate the phenomenon, the scientists were able to test its effect on pollinators, in this case foraging bumblebees. Their findings, published in the journal *Nature*, demonstrate that bees are able to see the blue halo and use it as a signal to locate flowers more efficiently.

> "The presence of these disordered photonic structures on their petals provides an alternative way to produce signals that attract insects."
> Ullrich Steiner

The researchers recreated blue halo nanostructures and used them as surfaces for artificial flowers. In a "flight arena," they tested how bumblebees respond to surfaces with and without halos. Their experiments showed that bees can perceive this difference, and find the surfaces with halos more quickly – even when both types of surfaces were colored with the same black or yellow pigment. Using rewarding sugar solution in one type of artificial flower, and bitter quinine solution in the other, the scientists also found that bees were able to use the blue halo to learn which type of surface held a reward.

The researchers say that these findings open up new opportunities for the development of surfaces that are highly visible to pollinators, as well as exploring just how living plants control the levels of disorder on their petal surfaces.

Reference

Moyroud, E.; Wenzel, T.; Middleton, R.; Rudall, P.J.; Banks, H.; Reed, A.; Meller, G.; Killoran, P.; Westwood, M.M.; Steiner, U.; Vignolini, S.; Glover, B.J. Disorder in convergent floral nanostructures enhances signalling to bees. Nature. 2017, 550, 469.

On and off

Using light to control nanoreactors

Biochemical processes in nature often rely on a system being pushed out of equilibrium before automatically returning to its resting state. One such example is the mechanism by which light receptors operate in the human eye, which has inspired NCCR Bio-Inspired Materials researchers to develop nanoreactors that function using the same principle.

Novel artificial light-responsive catalytic nanoscale systems use retinal receptors as their blueprint.

A molecule within retinal receptors changes its structure when irradiated with light, and an enzymatic reaction subsequently converts the molecule back into its original form. Without this capacity to revert back to their initial state, the receptor cells would not be able to sense light repeatedly.

NCCR scientists at the Adolphe Merkle Institute, along with colleagues at the Swiss Federal Laboratories for Materials Science and Technology (Empa) in St Gallen, adopted this as their blueprint for developing artificial light-responsive catalytic nanoscale systems.

"We were intrigued by a novel class of photoswitches called Donor-Acceptor-Stenhouse-Adducts (DASAs), that colleagues at the University of California, Santa Barbara, have developed," explains NCCR Principal Investigator Professor Nico Bruns. "They switch from a less polar resting state to a more polar isomer in presence of visible light, and return back to their resting state when the light is switched off."

Bruns and his team integrated such DASA molecules into the membrane of polymer nanocapsules. Upon irradiation with light, the DASAs switch, increasing the polarity of the capsule membrane. As a result, the capsules become permeable for water-soluble substances. This effect can be used to trigger the release of cargo from the nanocapsules. More intriguingly, capsules that hosted enzymes, in other words, biological catalysts, could be switched from an inactive state in the dark to a catalytically active state when irradiated with visible light. This active state lasts as long as light is present. Once returned to darkness, these nanoreactors automatically revert back to their original state with no catalytic activity. DASAs exist in several colors, which allowed the researchers to create nanoreactors that switch on in response to light of a specific color, such as white, red, or green. By encapsulating different enzymes in different nanocapsules, that can be activated by the various colors, a system was designed that can control and orchestrate enzymatic cascade reactions, kick-started by the different colored lights.

> "We could create light-responsive drug delivery nanosystems that could be activated by irradiation of tissue through the skin." Nico Bruns

Not every medication can be swallowed or pumped into the body with a syringe. However, the skin – our largest organ – offers a large permeable surface that readily absorbs active substances. Nicotine replacement, pain therapy, or contraception drugs are already applied through the skin using patches. "Light switches can be used for the entire spectrum between the wavelengths of 450 and 700 nanometers, in other words, colored light from blue to red," notes Empa researcher Dr. Luciano Boesel. "This allows one to control the release of several drugs or complex reaction cascades." The Empa researchers are considering these nanocapsules for use in light-switchable patches for transdermal drug delivery. This future development would enable, for instance, a non-invasive delivery method of essential drugs for premature babies. By embedding drug-filled, light-switchable nanocontainers into patches, the team aims to create the next generation of light-controlled transdermal drug delivery systems.

Work on the concept of light-switchable nanoreactors is being pursued in the second phase of the NCCR. The nanoreactors could be used to produce pharmaceutical products on demand, for example within a cell, or to produce active compounds such as drugs during medical treatment in a controlled fashion.

"We have created a platform technology that is very versatile. For instance, we will investigate how to equip polymers with DASA types that switch at wavelengths that span the whole visible spectrum, ideally also reaching the near infrared region," Bruns reveals. "This could be very beneficial as infrared light penetrates deeper into tissue than visible light. This way, we could create light-responsive drug delivery nanosystems that could be activated by irradiation of tissue through the skin."

Reference

Rifaie-Graham, O.; Ulrich, S.; Galensowske, N.F.B.; Balog, S.; Chami, M.; Rentsch, D.; Hemmer, J.R.; Read de Alaniz, J.; Boesel, L.F.; Bruns, N. Wavelength-Selective Light-Responsive DASA-Functionalized Polymersome Nanoreactors. Journal of the American Chemical Society. 2018, 140, 8027.

Spider stealth

Delivering cancer vaccines to the heart of immune cells

In the fight against cancer, researchers have turned to vaccines that stimulate the immune system to identify and destroy tumor cells. NCCR Bio-Inspired Materials scientists have developed artificial spider silk microcapsules that could boost the potency of these vaccines.

Artificial spider silk could lead to more efficient delivery systems for cancer vaccines.

Cancer treatment vaccines, or therapeutic vaccines, are designed to boost the body's natural defenses to fight the disease. The desired immune response, however, is not always guaranteed. In order to strengthen the efficacy of these vaccines – in particular on T lymphocytes, which are specialized in the detection of cancer cells – NCCR researchers from the Universities of Geneva and Fribourg, as well as the Ludwig-Maximilians University in Munich and the University of Bayreuth in Germany, and the German company AMSilk, have developed artificial spider silk microcapsules capable of delivering a vaccine directly to immune cells.

The human immune system is largely based on two cell types: B lymphocytes, which produce the antibodies needed to defend against various infections, and T lymphocytes. When it comes to cancer and certain infectious diseases such as tuberculosis, T lymphocytes must be stimulated in order to take action. However, their activation mechanism is more complex than that of B lymphocytes: to trigger a response, it is necessary to use a peptide, a small piece of protein that, if injected alone, is rapidly degraded by the body before reaching its target.

"To develop immunotherapeutic drugs effective against cancer, it is essential to generate a significant response of T lymphocytes," says NCCR Principal Investigator Professor Carole Bourquin, a specialist in antitumor immunotherapies at the University of Geneva's faculties of medicine and science, who directed this project. "As the current vaccines only have a limited influence on T-cells, it is crucial to develop other vaccination procedures."

The researchers chose to use synthetic spider silk biopolymers – a lightweight, biocompatible, non-toxic material that is highly resistant to degradation from light and heat. "We recreated this special silk in the lab to insert a peptide with vaccine properties," explains Professor Thomas Scheibel, a spider silk specialist from the University of Bayreuth who participated in the study. "The resulting protein chains are then salted out to form injectable microparticles."

Silk microparticles form a transport capsule that protects the vaccine peptide from rapid degradation and delivers the peptide to the center of the lymph node cells, thereby considerably boosting T lymphocyte immune responses. "Our study has proved the validity of our technique," reveals Bourquin. "We have demonstrated the effectiveness of a new vaccination strategy that is extremely stable, easy to manufacture, and easily customizable."

The synthetic silk biopolymer particles demonstrate a high resistance to heat, withstanding over 100°C for several hours without damage. In theory, this system would make it possible to develop vaccines that do not require adjuvants and cold chains – an undeniable advantage, especially in developing countries where the preservation of vaccines can be of great difficulty. One limitation, however, is the size of the microparticles: while the concept is in principle applicable to any peptide, as these are all small enough to be incorporated into silk proteins, further research is needed to see if it is also possible to incorporate the larger antigens used in standard vaccines, especially in those against viral diseases.

The properties of spider silk make it a particularly interesting product: it is biocompatible, solid, thin, biodegradable, resistant to extreme conditions, and even antibacterial. A wide variety of applications, including wound dressings or sutures, may be possible. The process developed by the NCCR researchers and their colleagues could also be applied to preventive vaccines to protect against infectious diseases, and constitutes an important step towards vaccines that are stable, easy to use, and resistant to the most extreme storage conditions.

Reference

Lucke, M.; Mottas, I.; Herbst, T.; Hotz, C.; Römer, L.; Schierling, M.; Herold, H.M.; Slotta, U.; Spinetti, T.; Scheibel, T.; Winter, G.; Bourquin, C.; Engert, J. Engineered hybrid spider silk particles as delivery system for peptide vaccines. Biomaterials. 2018, 172, 105.

Stretching molecules

Using theory to predict reality

NCCR Bio-Inspired Materials researchers at the University of Geneva have been able to to fill a gap in theoretical knowledge surrounding the force-response of single macromolecules by developing models to predict and explain the results of practical experiments carried out using a variety of techniques.

Researchers studied the force-responsive properties of single polymer chains.

Scientists have been using atomic force microscopy (AFM), a high-resolution imaging technique, to visualize nanometer-sized objects and even individual molecules since the 1980s. Near the turn of the millennium, researchers discovered a new area of application for atomic force microscopy: single-molecule force spectroscopy (SMFS). As its name suggests, SMFS can be used to study the mechanical properties of individual molecules by measuring their response when exposed to mechanical force. While the first experiments were carried out with biological molecules, DNA for example, this type of spectroscopy has more recently also been used to analyze polymers.

NCCR Principal Investigator Professor Michal Borkovec and postdoctoral researcher Dr. Milad Radiom, together with the rest of their group at the University of Geneva, employed SMFS in order to gain a better understanding of the effect of a chemical environment on the mechanical properties of single polymer chains. The scientists also examined chain rupture and conformational transitions within the polymer chain in response to mechanical force, probing on a molecular level how much force is required in order for chemical bond cleavage or other changes to take place. They used the SMFS technique to investigate the force-extension relationships of polystyrene – one of the most widely used plastics – in different organic solvents to determine at which point the molecule chains rupture.

> "One really important outcome we have found is that, in fact, these models are actually rather accurate."
> Michal Borkovec

While much practical research has been done on the force responsiveness of single molecules, few theoretical models exist in this field. The NCCR researchers investigated how theoretical work can help to put the results of these force experiments into the contexts of other, more established theories and parameters. The scientists were indeed able to develop a model showing to what extent the chemical environment influences the force-extension behavior of a polymer molecule. The group also interrogated the validity of such formulae. "One really important outcome we have found is that, in fact, these models are actually rather accurate," Borkovec reveals.

These theoretical studies were inspired by practical experiments, with the goal of helping to understand and interpret their results. A thorough comprehension of the force-extension relationship of single polymer chains is crucial for the field of soft matter, for instance for work on rubber elasticity, the swelling of polymer brushes, muscle action, or the mechanoresponsive polymers made by other NCCR researchers in which so-called mechanophores are included to serve as weak links. According to Borkovec, however, "the theoretical studies create more questions than answers," opening up new opportunities for further research.

Reference

Radiom, M.; Maroni, P.; Borkovec, M. Influence of solvent quality on the force response of individual poly(styrene) polymer chains. ACS Macro Letters. 2017, 6, 1052.

Quick switch

Stealthy sea creatures inspire color-changing system

Many animals have the ability to change their appearance so that they can blend in with their environment and hide, or make themselves more visible. NCCR Bio-Inspired Materials Principal Investigator Professor Marco Lattuada and his group at the University of Fribourg are aiming to create materials that replicate this ability. Their project focuses specifically on the capacities of squids and octopuses, which can rapidly change the colors of their skin.

Squid are known for their capacity to change color rapidly, reacting to circumstances and the environment.

Of course, in order to mimic, one must first understand the principles and processes underlying the stimuli-responsive color-changing systems in the animals. Special cells called chromatophores play a central role in the color-changing systems of squids and octopuses. These cells contain color pigments in small pockets located in the center of the cells. The pockets are controlled by muscular contractions, and the animals are able to change their size, so that the colored pigments can be spread from a small point to a larger area. Because the skin contains cells with pigments of many different colors, the animals are able to change their skin color into an array of hues, rather than simply turning one color on and off.

Lattuada's project seeks to develop materials that replicate this mechanism, or in other words, to create artificial cells capable of changing the area occupied by colors. To achieve this, researchers first dispersed colored magnetic nanoparticles in small droplets of water. In the absence of an external stimulus, the particles were homogeneously distributed in the droplets, giving them a brown appearance. By contrast, when a magnet was placed close to the droplets, it attracted the particles, so that they accumulated on the side of the droplet near the magnet. Much like in the natural model, the remaining portion of the droplets became colorless. While the size of the droplets remained the same, the area occupied by the colored particles changed.

> "One could imagine doing this with other kinds of stimuli, such as electric fields, so that you have an electric activated system." Marco Lattuada

The next step was to embed these droplets in a polymer matrix. This made it possible to fix the water droplets in their position, while the magnetic color particles were still able to circulate throughout the water droplets. The scientists succeeded in making a colored polymer material that became clearer when a magnet was approached.

"The material goes from dark to clear using a simple mechanism," sums up Lattuada, adding, "because of its simplicity, it could be used in a variety of ways."

Next, Lattuada hopes to extend this mechanism using different colorants in water, so that the material could change from dark to blue, for instance. He also states that "one could imagine doing this with other kinds of stimuli, such as electric fields, so that you have an electric activated system." Another major step would be to replicate the rest of the behavior of the animals – that is, the ability to not only change color, but to do so in response to the coloring of the immediate environment. Such a system, however, requires a much more sophisticated approach, as it would be necessary to first detect the other color before imitating it.

Possible applications for these color-changing materials include practical and aesthetic ones. They could be integrated into materials and used as a safety feature by recognizing properties of a system and signaling these with a change in color, for example in paper money. On a completely different note, it is also easy to imagine how such a technology could be used simply for the enjoyment of it. "Having something that can visually change color in response to stimuli could be a lot of fun in fashion, for example," concludes Lattuada.

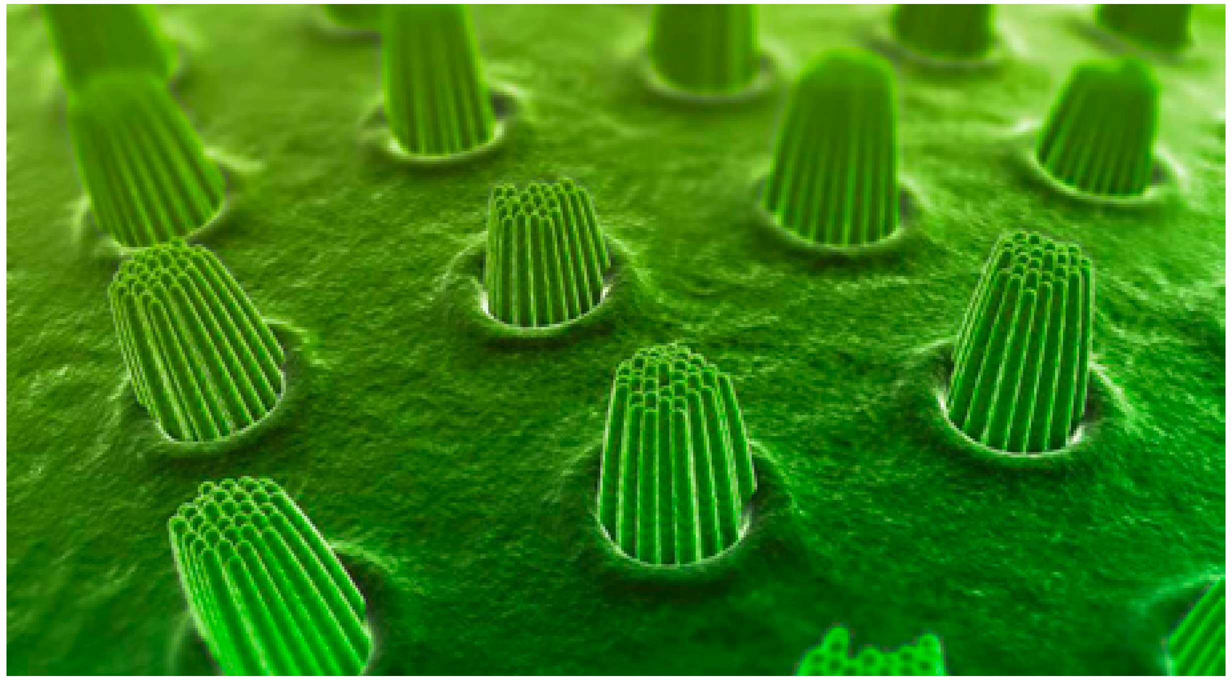
Reference

Isapour, G.; Lattuada, M. Bioinspired stimuli-responsive color-changing systems. Advanced Materials. 2018, 30, 1707069.

Mechanically responsive polymers

Polymers that give early warning signs

NCCR researchers at the Adolphe Merkle Institute are investigating ways to create polymer materials that visually signal mechanical stress without being triggered by other forms of energy, such as light or heat. Potential applications for such materials include built-in monitors – for instance in a bridge or plane – that send visual warning signs before a part fails, or enabling engineers to map stresses in parts under load in order to help them design these better.



In the inner ear, the motion of hair cells caused by sound triggers an electrical signal.

When placed under mechanical stress, every polymer will eventually deform and, at some point, break. For a long time, this was seen as a problem to be solved. About 15 years ago, however, Professor Christoph Weder, Principal Investigator at the Adolphe Merkle Institute, and his group began to think about this from a different perspective; the researchers asked themselves if this perceived weakness could, in fact, be exploited in a useful way. Their first breakthrough came with the invention of mechanochromic polymers, which change their color or fluorescence color when deformed and are useful to visually signal applied mechanical stresses. This concept mimics processes that can be found in nature in various forms: in many different contexts, nature uses mechanochemical transduction, that is, the transformation of mechanical into chemical signals. For example, in the inner ear, the motion of hair cells caused by sound triggers an electrical signal. Other scientists in the field then invented so-called mechanophores that can be integrated into polymer chains. These mechanically active motifs are designed to undergo chemical reactions when the polymer is deformed, which in turn produce a color or fluorescence color change or even cause the material to glow. However, the approach has one inherent, fundamental limitation: the chemical reaction that is activated by mechanical force can usually also be set off by other forms of energy, most notably light or heat. Thus, if a section of a mechanochromic polymer changes color, it is not necessarily clear whether it has been deformed or if it has been exposed to too much sunlight, for instance.

Addressing this problem, NCCR postdoctoral researcher Yoshimitsu Sagara – now an Assistant Professor at Hokkaido University in Japan – and Weder devised a mechanophore that is selectively activated by mechanical force. “Unlike other mechanophores, it does not undergo a chemical reaction," explains Sagara. "Instead, its functional mechanism is purely mechanic and can therefore not be triggered by other stimuli."

This new mechanophore is based on a rotaxane – a mechanically interlocked molecule consisting of a ring-like part that is threaded onto a dumbbell. Sagara attached a fluorescent dye to the cycle and placed a motif that quenches the dye’s fluorescence in the middle of the dumbbell’s axle. In the idle state, the dye and the quencher are close to each other, so that the dye’s fluorescence is switched off. Putting two chemical handles on the rotaxane – one on the cycle and one on the dumbbell – enabled the scientists to incorporate the new rotaxane mechanophore into polymer molecules. When such polymers are deformed, mechanical stress is transferred from the polymer chains to the mechanophores, so that the fluorophore-carrying cycle slides away from the quencher and the fluorescence is turned on. The researchers embedded their rotaxane in an elastic polymer and showed that the fluorescence was indeed turned on when the material was stretched, and switched off when the force was removed and the material contracted. They also confirmed that their new polymers only start to glow when deformed and that the luminescence cannot be turned on by heating or activating the material otherwise.

Having demonstrated that the approach works and established a synthetic strategy for rotaxane mechanophores, the team has created several rotaxanes that glow in different colors. One remaining caveat is that the rotaxane synthesis is extremely complex. “It has taken us two and a half years to make a few milligrams of the first rotaxane, and its synthesis requires about 25 different synthetic steps,” says Weder, adding that the design must be simplified in order for it to be used efficiently and on a larger scale. Precisely this optimization is the current focus of collaborative research efforts of members of Weder and Sagara’s groups. They are aiming to change the architecture and think that they will be able to reduce the number of synthetic steps to five or even fewer. Finally, they want to expand the idea to materials with mechanophores that change their color, instead of their fluorescence color. Such motifs would enable sensors that can be inspected by the naked eye, which would thus be more useful for practical applications.

Reference

Sagara, Y.; Karman, M.; Verde-Sesto, E.; Matsuo, K.; Kim, Y.; Tamaoki, N.; Weder, C. Rotaxanes as Mechanochromic Fluorescent Force Transducers in Polymers. Journal of the American Chemical Society. 2018, 140, 1584.

Bee venom

Building a gateway to destroy pathogens

NCCR researchers are drawing inspiration from the immune response of mammals to address the resistance of cancer cells and other pathogens to current forms of treatment, as well as to find a simpler method for protein analysis.

Researchers began using a bee venom peptide to create a pathway to destroy pathogenic cells.

The membrane attack complex (MAC) is a strictly regulated part of the innate immune response of mammals. When the body detects a pathogen, a cascade of events is launched that ultimately prompts proteins to assemble into a pore on the surface of the pathogen. This pore perforates the membrane and destroys the pathogenic cells.

NCCR researchers at the Adolphe Merkle Institute aim to develop molecules similar to the MAC that can self-assemble into pores on cell membranes when triggered. Such pores could be used to combat the growing resistance of bacteria to traditional antibiotics or of cancer cells to chemotherapy. Once amassed on a pathogen, the pores would either kill the cells or serve as a pathway for drug delivery directly into the cell. Because this approach mimics the body's innate immune response, it would be difficult for a biological system to develop a resistance against it.

The scientists also imagine that self-assembling pores could provide the key for a simpler method to analyze protein molecules that may indicate certain diseases (so-called biomarkers).

While some pores of this kind have already been produced in the lab, NCCR Principal Investigator and AMI Professor Michael Mayer's group is focused on engineering a larger hybrid protein pore with a wide range of possible diameters. As in the MAC, the idea is to drive proteins together to assemble into a pore. "Ideally, we could decide ourselves how many proteins assemble, so that there is greater variability in the pores," explains Mayer. In other words, the pore diameter should be programmable, but also stable.

The researchers started by using the peptide mellitin, the main active ingredient in bee venom toxin, as it is straightforward to work with: it can be purchased with its DNA attached, and large quantities can readily be synthesized as needed; it is well understood; and a variant that creates larger pores already exists. These pores, however, are not well-defined, so the use of mellitin for this purpose is not ideal. To overcome this problem, the scientists designed a modified form of ceratotoxin A (CtxA), a peptide found in the medfly *Ceratitis capitata*, which has proven to be more effective. In contrast to pores found in nature, CtxA can be attached to a scaffold to form a modular system, increasing the pore's functionality. The modular system provides functional sites to which other structures can be synthesized. Consequently, various aspects can be changed without having to modify the peptide itself.

> "This could provide a possibility to revisit old drugs that may have been promising but could not get past the membrane." Michael Mayer

So far, the team has successfully managed to form pores of the desired size. According to Mayer, the next goal is to make these pores stable, that is, to keep them in place once formed on a membrane. One promising result has been a pore that stayed stable for forty minutes. The researchers will continue to investigate better ways to anchor the peptide in its transmembrane conformation. In addition to launching cell-killing experiments, which may lead in various directions for applications, Mayer sees many opportunities for implementing this technology. "This could provide a possibility to revisit old drugs that may have been promising but could not get past the membrane," Mayer elaborates. In this case, the pores could become one of a suite of strategies for effective drug delivery. And while these hybrid protein pores have useful functions in and of themselves, they also open up an even wider array of possibilities for future development and use.

Reference

Fennouri, A.; Mayer, S.F.; Schroeder, T.B.; Mayer, M. Single channel planar lipid bilayer recordings of the melittin variant MelP5. BBA Biomembranes. 2017, 1859, 2051.

169

Researchers

including associate groups

CHF 27.7 million

of funding over four years including CHF 12 million from the SNSF

32 Nationalities

Switzerland, Spain, France, Germany, Belgium, Hungary, Croatia, USA, UK, Slovenia, Ukraine, India, Italy, Russia, Brazil, Turkey, Iran, Indonesia, Nigeria, Australia, Serbia, Portugal, Luxemburg, Costa Rica, Greece, Vietnam, Bulgaria, China, Cuba, Japan, Kosovo, Taiwan

Partners

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

35

Publications

in journals with an impact factor of over 9 – including Nature, Nature Materials, Proceedings of the National Academy of Sciences, Nature Communications, Advanced Materials, Journal of the American Chemical Society, and Angewandte Chemie

Note: All figures between June 1, 2014, and February 28, 2018

In brief

Swiss Youth in Science

The NCCR participated in the 2018 Chemistry and Materials Science Study Week organized by Schweizer Jugend Forscht (Swiss Youth in Science), a program that offers high school students from all over the country the opportunity to spend a week in a research lab at an academic institution or at a company performing a short research project.

Students presented their work on chemistry and materials at a final event in Fribourg.

This year, five NCCR groups from the Adolphe Merkle Institute and the University of Fribourg's Department of Chemistry hosted students. The Center also coordinated the stay and activities of all participants in Fribourg, and organized the closing ceremony of the Study Week, bringing together the 39 participants, as well as their families and hosts, altogether more than 100 people.

NCCR staff have now gathered three times in the village of Charmey in the Swiss Prealps.

Annual Center Conference

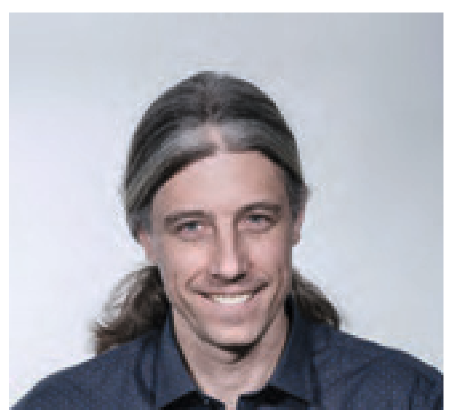
The third and fourth Annual Center Conferences (ACC) were held in Charmey in September 2017 and 2018, bringing together around 80 participants each time.

The conferences included lectures on topics ranging from ethics in science to launching a company and successful negotiating. These meetings were also opportunities for the Principal Investigators joining the NCCR in Phase II – Professors Esther Amstad (EPFL), Harm-Anton Klok (EPFL), Aleksandra Radenovic (EPFL), Stefano Vanni (University of Fribourg), Eric Dufresne (ETHZ) – to present their work. The ACCs also included poster sessions during which the Principal Investigators, postdoctoral researchers, and students presented and discussed their projects, a Women in Science (WINS) symposium, and teambuilding activities.

Tenured

NCCR Principal Investigator Professor Nico Bruns (Adolphe Merkle Institute) has been appointed as a full Professor at the University of Strathclyde's Department of Pure and Applied Chemistry (United Kingdom).

Bruns, who was an SNSF Professor in macromolecular chemistry at the Adolphe Merkle Institute in Fribourg since 2013, took up his position in Glasgow in October 2018. He will continue to participate in the NCCR as a Principal Investigator.



Nico Bruns is now a professor at the University of Strathclyde.

High-impact publications

Sagara, Y.; Karman, M.; Verde-Sesto, E.; Matsuo, K.; Kim, Y.; Tamaoki, N.; Weder, C. Rotaxanes as mechanochromic fluorescent force transducers in polymers. Journal of the American Chemical Society. 2018, 140, 1584.

Pal, S.; Lucarini, F.; Ruggi, A.; Kilbinger, A.F.M. Functional metathesis catalyst through ring closing enyne metathesis: One pot protocol for living heterotelechelic polymers. Journal of the American Chemical Society. 2018, 140, 3181.

Schaffner, M.; Faber, J. A.; Pianegonda, L.; Rühs, P. A.; Coulter, F.; Studart, A. R. 3D printing of robotic soft actuators with programmable bioinspired architectures. Nature Communications. 2018, 9, 878.

Conley, G.M.; Aebischer, P.; Nöjd, S.; Schurtenberger, P.; Scheffold, F. Jamming and overpacking fuzzy microgels: Deformation, interpenetration, and compression. Science Advances. 2017, 3, e1700969.

Froufe-Pérez, L.S.; Engel, M.; Sáenz, J.J.; Scheffold, F. Band gap formation and Anderson localization in disordered photonic materials with structural correlations. Proceedings of the National Academy of Sciences USA. 2017, 114, 9570.

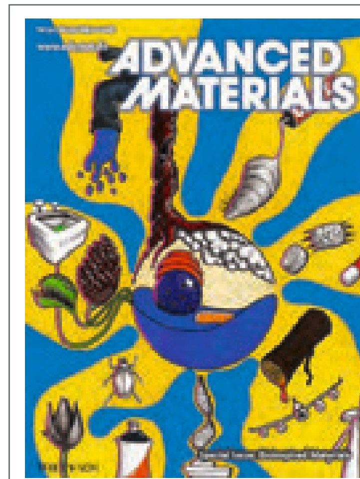
Moyroud, E.; Wenzel, T.; Middleton, R.; Rudall, P.J.; Banks, H.; Reed, A.; Meller, G.; Killoran, P.; Westwood, M.M.; Steiner, U.; Vignolini, S.; Glover, B.J. Disorder in convergent floral nanostructures enhances signalling to bees. Nature. 2017, 550, 469.

Wilts, B.D.; Apeleo-Zubiri, B.; Klatt, M.A.; Butz, B.; Fischer, M.G.; Kelly, S.T.; Spieker, E.; Steiner, U.; Schröder-Turk, G.E. Butterfly gyroid nanostructures as a time-frozen glimpse of intracellular membrane development. Science Advances. 2017, 3, e1603119.

Cagno, V.; Andreozzi, P.; D'Alicarnasso, M.; Silva, P.J.; Müller, M.; Galloux, M.; Le Goffic, R.; Jones, S.T.; Vallino, M.; Hodek, J.; Weber, J.; Sen, S.; Janeçek, E.R.; Bekdemir, A.; Sanavio, B.; Martinelli, C.; Donalisio, M.; Rameix Welti, M.A.; 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. 2018, 17, 195.

Lucke, M.; Mottas, I.; Herbst, T.; Hotz, C.; Römer, L.; Schierling, M.; Herold, H.M.; Slotta, U.; Spinetti, T.; Scheibel, T.; Winter, G.; Bourquin, C.; Engert, J. Engineered hybrid spider silk particles as delivery system for peptide vaccines. Biomaterials. 2018, 172, 105.

Milosevic, A.; 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 International Edition. 2017, 56, 13382.



Special issue

A special edition on the topic of bio-inspired materials of the leading journal *Advanced Materials* – edited by NCCR Bio-Inspired Materials Principal Investigator Professor Nico Bruns and his University of Cambridge colleague Dr. Silvia Vignolini – was published in May 2018.

The issue presents bio-inspired materials across all length scales, including wood-based water purification systems, mussel protein inspired glues, diatoms that encapsulate drugs, fiber-reinforced composites that indicate damage by bleeding, helical cellulose nanocrystals for optical applications, pigments and coatings that mimic the structural colors of insects and plants, and architecture inspired by the moving parts of plants. Papers include contributions from the groups of NCCR Principal Investigators Professors Alke Fink, Barbara Rothen-Rutishauser, Christoph Weder, Michael Mayer, Marco Lattuada, André Studart, and Ullrich Steiner.

Professor Bert Meijer of the Eindhoven University of Technology.

Conferences

The Center was instrumental in keeping the Gordon Research Conference (GRC) on Bioinspired Materials in Switzerland (Les Diablerets, Vaud).

The 2018 GRC's program featured four NCCR Principal Investigators alongside an international line-up of distinguished investigators engaged in research on bio-inspired materials. The GRCs are one of the world's premier scientific meeting series and cover a wide range of research fields at the frontier of the biological, chemical, and physical sciences.

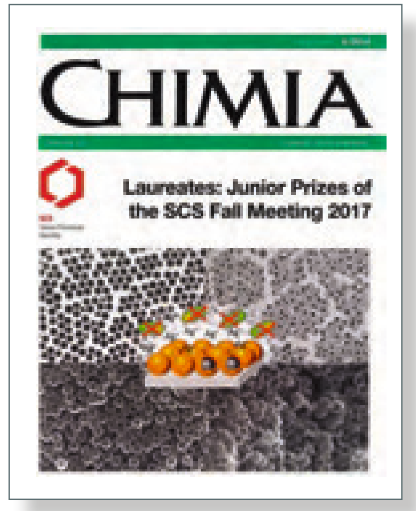
NCCR staff members Dr. Lucas Montero and Dr. Stephen Schrettl organized the first-ever Swiss Conference on Supramolecular Polymers at the Adolphe Merkle Institute in November 2017. The one day event's goal was to provide a forum for the 50 attendees to discuss their latest results, exchange ideas, and find synergies to establish future collaborations. Speakers at the conference included Professor Bert Meijer of the Eindhoven University of Technology in the Netherlands, one of the most well-renowned specialists in the field, NCCR Director Professor Christoph Weder, and five other professors from Swiss universities.

Awards

NCCR PhD student Sarah-Luise Abram (Fromm group, University of Fribourg) was the winner of the **SCS-DSM Award for the Best Poster presentation** in the Division of Polymers, Colloids & Interfaces of the Swiss Chemical Society Annual Meeting 2017, leading to an invitation to publish a paper and to feature on the cover of the journal *Chimia*. Her colleague Laura Neumann (Polymer Chemistry & Materials group, Adolphe Merkle Institute) took home the **Swiss Chemical Society Polycoll Best Oral Presentation Award** at the 2018 SCS meeting for her talk on the "Dynamics and Welding Behavior of Metallosupramolecular Polymer Films."

Céline Calvino (Polymer Chemistry & Materials group, Adolphe Merkle Institute) was the winner of one of the five **Swiss Nanotechnology PhD Awards** presented at the Swiss NanoConvention 2018 in Zurich. She was recognized for her work on mechanochromic materials based on non-covalent interactions.

NCCR Principal Investigators Professors Barbara Rothen-Rutishauser and Alke Fink were awarded the **2017 CUSSTR Prize** by western Switzerland's university commission for health and safety for helping improve nanosafety. Along with their colleagues Amela Groso, Thierry Meyer, and Professor Heinrich Hofmann of Lausanne's Federal Institute of Technology (EPFL), the co-chairs of the Adolphe Merkle Institute's BioNanomaterials group were recognized for their development of a nanomaterials decision tree. The researchers adapted and developed an intuitive method for nanomaterial risk management in laboratories in which activities related to nanomaterials are classified



NCCR research was featured on the cover of *Chimia*.

into three levels. They also provide concrete preventive and protective measures and recommended associated actions.

NCCR Principal Investigator Professor Katharina Fromm (University of Fribourg) was elected a **member of the European Academy of Sciences** in December 2017. The European Academy of Sciences is a non-governmental organization of distinguished scholars and engineers who perform forefront research and develop advanced technologies, united by a commitment to promoting science and technology and their essential roles in fostering social and economic development.

Summer research program

In 2017 and 2018, the Undergraduate Research Internships program hosted a total of 38 students from 16 different universities, most notably from the United States and the United Kingdom.

Eleven NCCR groups, as well as one associate group, served as hosts for the summer interns. The students not only performed a three-month research project, but also attended a special series of seminars on NCCR-related topics delivered by PhD students and postdoctoral researchers and took part in team-building events. The participants were also asked to prepare poster presentations describing their projects, which were shown

The NCCR undergraduate class of 2018.

at the NCCR Summer Party in Fribourg during a special session. Amber Barron of the University of Utah was awarded the best poster prize 2017, while Ava LaRocca of the Massachusetts Institute of Technology was the winner this summer.

Discovering structural color at Zurich Zoo.

Going Wild!

The NCCR was present at the Zurich Zoo's Going Wild! weekend in September 2017 and 2018.

As part of the "science inspired by nature" exhibits on show, the Adolphe Merkle Institute's Soft Matter Physics group was present both years, with butterflies and beetles on display to help explain structural color. In 2018, they were joined by ETHZ's Soft and Living Materials group. Also present this year was AMI's Polymer Chemistry & Materials group to demonstrate flexible polymers, as well as the Lattuada group from the University of Fribourg, which explained how to reinforce soft materials with magnetic nanoparticles. Other research groups participating over the weekend included staff from Switzerland's two Federal Institutes of Technology. This section of Going Wild! was organized in collaboration with the NCCR's Knowledge Transfer and Innovation manager.

TecDays

NCCR Principal Investigator Professor Barbara Rothen-Rutishauser (Adolphe Merkle Institute) joined over 50 other technology specialists for the TecDays organized by the Swiss Academy of Technical Sciences in Fribourg and Bern.

Students were invited to attend a variety of sessions on topics ranging from exoplanets to radioactive waste. Rothen-Rutishauser was on hand to present the intricacies of nanoscience and nanotechnology to six high school classes.

Students were given theoretical and experimental explanations about nanoscience.

Patrick Aebischer was a guest of the Fribourg Innovation Club.

Homecoming

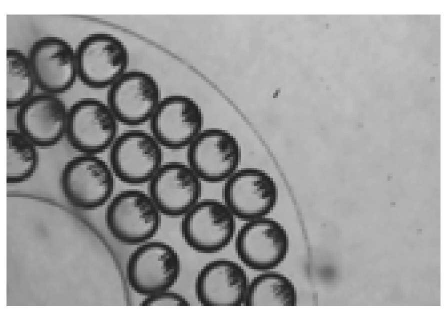
The former president of the Federal Institute of Technology in Lausanne (EPFL), Professor Patrick Aebischer, was a guest of the NCCR-supported Fribourg Innovation Club at the Adolphe Merkle Institute in December.

Aebischer, who gave up the EPFL presidency in 2017, grew up in Fribourg and began his medical studies there. The fireside chat focused largely on how the canton could improve its positioning as a center for innovation. The Center is one of the sponsors of the Innovation Club, which aims to help students develop and implement innovative ideas.

Imaging

NCCR Bio-Inspired Materials PhD student Golnaz Isapour (University of Fribourg) was the winner of the "video loop" category of the 2018 Swiss National Science Foundation's Scientific Image Competition.

Her video shows a microfluidic channel through which micro-sized polymer particles filled with black magnetic nanoparticles flow. With the aid of a magnet, the position and arrangement of the magnetic nanoparticles is changed. This material can be used to produce magnetic responsive sensors in which the color of the material changes by altering the strength or direction of the magnetic field.



Particles flow through a microfluidic channel.

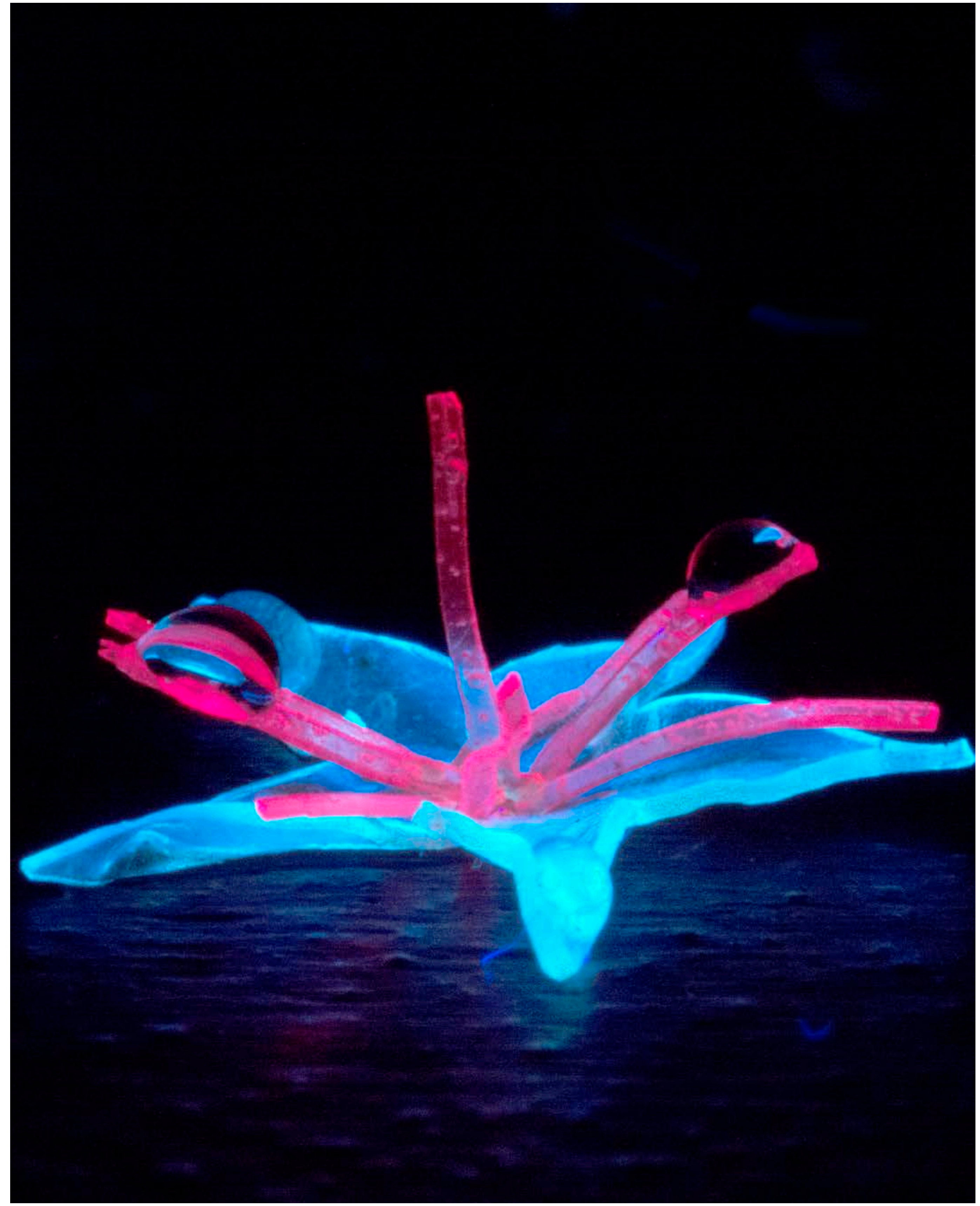
WINS

Two additional researchers joined the NCCR in 2018 as recipients of the Women in Science (WINS) postdoctoral fellowship.

Dr. Yendry Corrales was chosen to receive two years' funding on the basis of her interdisciplinary project "Nanostructured coatings formed by self-assembly of biomacromolecules complex mixtures based on the velvet worm secretion expelling mechanism," which is expected to foster collaborations within the NCCR. Dr. Corrales joined Principal Investigator Professor Alke Fink's group in spring.

Dr. Yendry Corrales presented her research project at the 2017 Annual Center Conference.

Dr. Iris Kramberger Tennie is the third recipient of the WINS fellowship. She joined the Center in June 2018 and is hosted by NCCR PI Professor Andreas Kilbinger's group to work on the development of stimuli-responsive copolymers containing MRI contrast agents. The outcomes of her project are expected to set the basis for new MRI techniques for cellular microenvironment sensing.



PIRE

International collaboration boosts NCCR education efforts

Researchers from the NCCR Bio-Inspired Materials and four American universities are collaborating to develop functional materials inspired by substances found in nature, while also offering international training opportunities in this domain, providing an additional boost to the NCCR's activities.

Pine cone structures are just one source of inspiration for PIRE projects.

A $5.5 Mio grant, awarded in September 2017 by the US National Science Foundation (NSF) as part of the Partnerships for International Research and Education program (PIRE), supports research and training activities at Case Western Reserve University, the University of Delaware, the University of Chicago, and the University of California, San Diego, all in the United States. The corresponding actions in Fribourg, led by the five NCCR groups at the Adolphe Merkle Institute (AMI), are enabled by a complementary CHF 1.5 million grant from the Swiss National Science Foundation (SNSF), which was implemented simultaneously. This was the first time that the SNSF joined as a partnering agency in the PIRE program, which is led by the American agency and aims to build research capacities through international collaborations, promote excellent science, and tackle some of today's most pressing research questions. In all, six professors at AMI – all of them NCCR Principal Investigators – 11 faculty members from the US partners, as well as 15 PhD students (10 in the US, five in Switzerland) are contributing to the program.

The Swiss team is led by Professor Christoph Weder, director of the NCCR Bio-Inspired Materials. Weder says, "the research beautifully combines the scientific competences of the US and Swiss groups, and the exchange programs provide unique training opportunities for the students."

> "The exchange programs provide unique training opportunities for the students." Christoph Weder

According to Weder, the training activities established by the PIRE collaboration notably complement and integrate with the student exchange programs and other training activities established by the NCCR. Students will gain exposure to themes cutting across chemistry, polymers, physics, biology, and engineering in the development of multi-functional, active materials. Mentoring, diversity, cultural competency, globalization, and effective scientific communication are also emphasized as critical elements of the PIRE.

Academically, the students will receive fundamental training in these domains. This education will be supplemented by research exchanges, enabling students and senior researchers to spend significant time abroad in the respective partner country.

Over the five years of the program, faculty and students in the US and Switzerland will study and develop materials that mimic, for example, the sticky and durable caddisfly silk, the adaptable skin of sea cucumbers, and a substance that directs cellular behavior. "We're studying materials and objects found in nature and then reducing the materials for practical use," states LaShanda Korley, Distinguished Associate Professor of Materials Science and Engineering at the University of Delaware and Principal Investigator on the project.

Alexandre Redondo was the first PhD student to join the PIRE collaboration on the Swiss side. As part of the AMI Soft Matter Physics group, he aims to develop polyurethane plastics reinforced with cellulose nanocrystals (nanocomposites) that mimic the mechanical properties of spider silk. The interdisciplinary nature of the projects was one of the reasons he joined. "I'm a chemist by training, so this is an opportunity to learn about other disciplines, as well as work with materials," he explains. Redondo will notably study the mechanical properties and crystalline structure of the polyurethane plastics he will assemble.

Other projects of the collaboration include the study of materials inspired by sea cucumbers, squids, and pine cones, as well as the development of artificial neurons for robot control and of mechanically adaptable functional fibers.

The materials during this project should eventually be tested in a worm-like robot that may one day burrow through the earth or building wreckage on search and rescue missions, crawl inside waterlines and oil and gas pipelines to inspect them, and, if miniaturized, deliver a stent or remove plaque by crawling through a blood vessel.

Mosquito bites are responsible for the transmission of the malaria parasite.

Innovation

From laboratory to market

NCCR Bio-Inspired Materials researchers are currently developing a new diagnostic method for malaria at the University of Fribourg's Adolphe Merkle Institute. This new tool could lead to fewer false positives, improve treatment protocols for patients, and help reduce healthcare costs.

The World Health Organization (WHO) estimates that in 2016, there were over 200 million cases of malaria globally, while nearly 450,000 people died because of the illness. Current WHO practices recommend diagnostic testing for all suspected cases of malaria before treatment is administered. "There are different reasons for this," says Dr. Jonas Pollard, head of the Hemolytics project. "You want to avoid overtreatment, boosting the resistance of the malaria parasite, and wasting resources, especially in countries where funding is scarce."

Rapid diagnostic testing, which was introduced in recent years, helps to distinguish between malarial and non-malarial fevers. Medical staff can then decide on an appropriate course of treatment. This inexpensive testing-strip solution has become a favored method of testing for malaria, especially in Africa, with around 270 million test kits sold worldwide in 2015. Nevertheless, this type of testing fails to detect infections in subjects whose blood contains only a low concentration of parasites, which is typical in asymptomatic carriers.

For countries where malaria has almost disappeared, the biggest concern is totally eradicating the disease. A person can be a carrier without displaying any physiological signs of infection. These untreated asymptomatic patients risk transmitting the disease further through mosquito bites, leading to fresh outbreaks of malaria. It is these carriers who are the prime target of the diagnostic method being developed. "You want to be able to check if someone is an asymptomatic carrier," Pollard points out. "That way you can stem the spread of the disease by further contamination, for example by carrying out checks at a border. Our method aims to be far more sensitive than the rapid diagnostic tests which are currently on the market."

The test developed by the NCCR researchers is based on a simple but ingenious principle: first, a blood sample is obtained, which in the case of infected patients contains a biomarker that the malaria parasite produces at every stage of its life cycle and that is present even if the patient displays no symptoms of infection. This biomarker also happens to be an efficient catalyst for polymerization reactions – just one molecule is enough to initiate and mediate the formation of many polymer molecules. Thus, when combined with a monomer, an appropriately worked-up blood sample from an infected patient will, unlike blood from healthy patients, catalyze the formation of polymer molecules, and because the reaction is conducted under conditions where the polymer formed precipitates from the mixture, the initially clear test liquid turns opaque. This optical change can be observed with the naked eye and also quantified by simple measurements.

The advantages of the method do not end there. The biomarker's concentration in a sample can be estimated quickly. This could be employed to determine if the condition of a patient being treated for malaria is improving. Another advantage is the stability of the products used for the test. Most rapid diagnostic tests that are currently on the market contain antibodies and require refrigeration to avoid rapid degradation, which is not always available in some regions where the disease is most common. The new diagnostic method has been tested with temperatures up to 50 degrees Celsius for several months and the relevant compounds remained stable. Its estimated cost is not more than other tests already in use.

> "The Hemolytics project is an example of how good ideas with properly-secured intellectual property can flourish with the appropriate mentoring and financial support." Eliav Haskal

With the active support of the NCCR, the researchers have been able to obtain funding from different sources to cover salaries and development costs, including a Bridge grant of CHF 130,000 from Innosuisse and the Swiss National Science Foundation as well as a grant from the Gebert Rüf Foundation for CHF 290,000. "The NCCR's support has been crucial in getting backing for this project," Pollard reveals. "I received help defining a preliminary business plan and finding initial business contacts, and coaching to refine my pitching. This work, particularly with the NCCR's Knowledge Transfer and Innovation Manager, Dr. Eliav Haskal, has also considerably facilitated the change of my mindset from scientist to entrepreneur."

"The Hemolytics project is an example of how good ideas with properly-secured intellectual property can flourish with the appropriate mentoring and financial support," explains Haskal. "With this project's focus on a solution with significant benefits for poor countries where malaria is widespread, as an example of 'social entrepreneurship,' it depends on support from foundations and government agencies. The NCCR, with its soft-skills training, innovation coaching, and a rich and vibrant local network, can provide an environment where these novel solutions can be refined and supported long enough to succeed."

Further seed money from the Swiss government has allowed the team to test their first prototype, developed in collaboration with Fribourg's engineering school, in a clinical setting in Brazil to see if it meets the needs of local laboratory technicians.

Pollard is optimistic that there is a market for this new technology, which is why an application for patent protection was filed in May 2016. "There are currently no tools on the market which allow for accurate and sensitive malaria diagnostic with high throughput," he adds. "Our product would fill a crucial niche in the elimination of this parasitic disease." Governments of affected nations and non-governmental organizations are among the potential clients. However, they will be only interested in a finished product says Pollard, given that they cannot afford to finance development work. "Ideally, the next stages of our research will lead to a device that can be used in the field, where it is needed most."

NCCR Bio-Inspired Materials spin-offs

Nanolockin (incorporated) – nanoparticle detection, Adolphe Merkle Institute
Hemolytics – malaria diagnostics, Adolphe Merkle Institute
Microcaps – uniform microencapsulation, ETHZ
Spectroplast – silicon 3D printing, ETHZ
FenX – highly porous foams for building insulation, ETHZ

Knowledge transfer

Promoting an innovation culture

The NCCR Bio-Inspired Materials, like all of the National Centers of Competence in Research, not only carries out fundamental research but also seeks to translate some of the knowledge generated into new technologies. The promotion of innovation and training in entrepreneurial skills is an essential element to achieve this goal.

Innovation, or the process of translating an idea into a product or service for which customers will pay, is an indispensable aspect of technology transfer. The promotion of innovation is therefore an important element within the NCCR, where students and postdocs are sensitized to the concepts and skills needed to innovate. Through a variety of mechanisms, actions, and programs, students and postdocs can adopt skills that should help them to successfully transfer technology to industry as academics, to innovate within companies as future employees, or to follow their own entrepreneurial visions.

"Teaching innovation to students and postdocs makes them aware of the enormous possibilities available to them to leverage their research in multiple ways, including research grants, collaborations with industry, or even becoming entrepreneurs," explains Dr. Eliav Haskal, the NCCR's Knowledge Transfer and Innovation Manager. "These aspects can be an asset when pursuing an academic career, and offer a different perspective on the importance of research in society."

"As the NCCR Bio-Inspired Materials develops novel materials, we are situated at the start of a product value chain, providing unique material properties for unmet needs in industry, but also for products which do not exist yet. Our research results are therefore excellent for generating new intellectual property and entrepreneurial ventures," he adds. "So far, five company spinoffs from the NCCR are in progress, two of which came out of the Adolphe Merkle Institute in Fribourg and three from Zurich's Federal Institute of Technology (ETHZ)."

> "Teaching innovation to students and postdocs makes them aware of the enormous possibilities available to them to leverage their research." Eliav Haskal

As the first NCCR led by the University of Fribourg, the NCCR Bio-Inspired Materials is developing an innovation culture in collaboration with the Fribourg School of Management (HEG-FR) and the Fribourg School of Engineering and Architecture (HEIA-FR) to access management and engineering students – as well as coaches and mentors – for new ventures. The "Association for Student Innovation," which comprises members

from the local universities and representatives from the canton's economic promotion agency, is an important element in this effort. "With the panoply of multidisciplinary students present at the Fribourg Pérolles campus, we are creating an environment that will foster student innovation, provide them with the needed skills from experts, and leverage the NCCR's research results successfully," says Haskal. As a concrete implementation of this vision, in collaboration with the HEG-FR, MBA students are introduced to NCCR research results, perform market studies, and develop initial business plans as part of a master's thesis program. This interdisciplinary cooperation is a fundamental aspect for stimulating innovation and creating new technology transfer possibilities.

The NCCR co-organized the first-ever Stimulating Student Innovation and Entrepreneurship Workshop in Switzerland in November 2017.

Activities

The NCCR co-organized the Stimulating Student Innovation and Entrepreneurship Workshop in November 2017 in Fribourg. This workshop, funded by the Swiss Academy of Engineering Sciences (SATW) and organized in collaboration with all of Fribourg's academic innovation drivers, brought 60 innovation professionals from more than 20 Swiss universities together to discuss their activities and best practices for the first time. With distinguished speakers from NTU Singapore, the Danish Technological University's Innovation Park Skylab, the Dean of Management from the University of St. Gallen, and representatives from cantonal and national innovation departments, the workshop nucleated a collaboration of Swiss universities on student innovation. The results of this workshop are being studied in collaboration with the HEG-FR to develop a model for how to stimulate innovation at Swiss universities, and the conference will be repeated in 2019.

As part of the new Specialized Master's program in Chemistry and Physics of Soft Materials, a new course on innovation was launched in the fall of 2017. The 13-session course was well received by the attending MSc and PhD students, adapted to be a one-day interactive seminar on Technology Transfer for PhD students, and also taught as an evening course as part of Innosuisse's Entrepreneurship Training.

The NCCR Proof-of-Concept Grant Program provides seed money and supports short-term projects to explore technological feasibility and probe the economic viability of inventions. NCCR researchers can request financial support and coaching assistance to create a prototype, demonstrate specific applications, assess pre-industrial feasibility, or identify market opportunities. Depending on the project and its needs, the invested amounts range from CHF 5'000 to 20'000 per project. To date, two NCCR projects have been supported, one of which is developing into an NCCR spinoff company.

A collaboration between the University of Fribourg, the Adolphe Merkle Institute (AMI), the Fribourg School of Engineering and Architecture (HEIA-FR), and the Fribourg School of Management (HEG-FR), the Association for Student Innovation financially supports the student-led Innovation Club, which consists of students from all of the local schools. The Innovation Club brings entrepreneur role models to speak and motivate students in Fribourg, runs design-thinking workshops, supports entrepreneurial idea pitching sessions, connects individuals for new ventures, oversees mentoring, and provides access to a network for entrepreneurial students. Past speakers include former EPFL president Professor Patrick Aebischer and the Nobel Prize in Chemistry laureate Professor Alan Heeger.

Equal opportunities

Propagating best practices at partner departments and institutions

Promoting and offering equal opportunities (EO) has always been one of the NCCR Bio-Inspired Materials' core initiatives since its launch in 2014. The Center's efforts have been recognized by the Swiss National Science Foundation, which highlighted the EO program as an example of best practice of the fourth series of NCCRs.

Equal opportunities roundtables have been a regular future of the NCCR since its launch.

With that encouragement, the Center is now seeking to broaden the impact of these successful activities by transferring them to affiliated departments at the University of Fribourg (home institution), as well as at the Federal Institutes of Technology in Zurich (ETHZ) and Lausanne (EPFL).

From the beginning, the vision of the NCCR Bio-Inspired Materials has been to ensure equal opportunities for all its participants, as well as to establish itself as a reference for the advancement of young female scientists and their integration in natural and life science disciplines. For the next funding phase, the EO program aims to reach out beyond the NCCR.

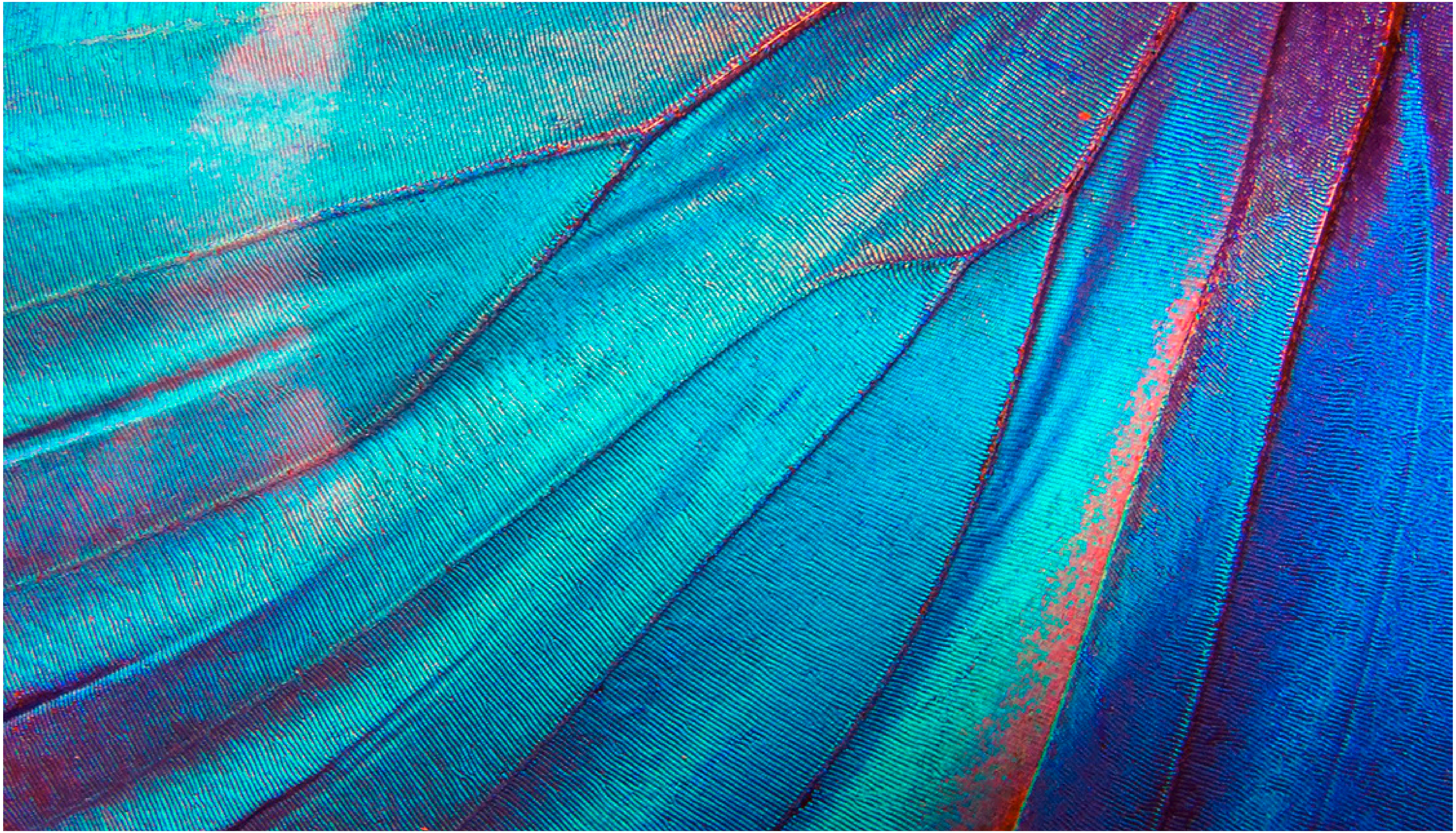
Principal Investigator and Faculty Delegate for the Advancement of Young Researchers and Women Professor Barbara Rothen-Rutishauser will lead this new venture. According to Rothen-Rutishauser, "the EO activities organized by our NCCR have received significant interest from unaffiliated students and postdocs at the departments involved in the Center", and "translating the most successful activities to these departments was a logical step."

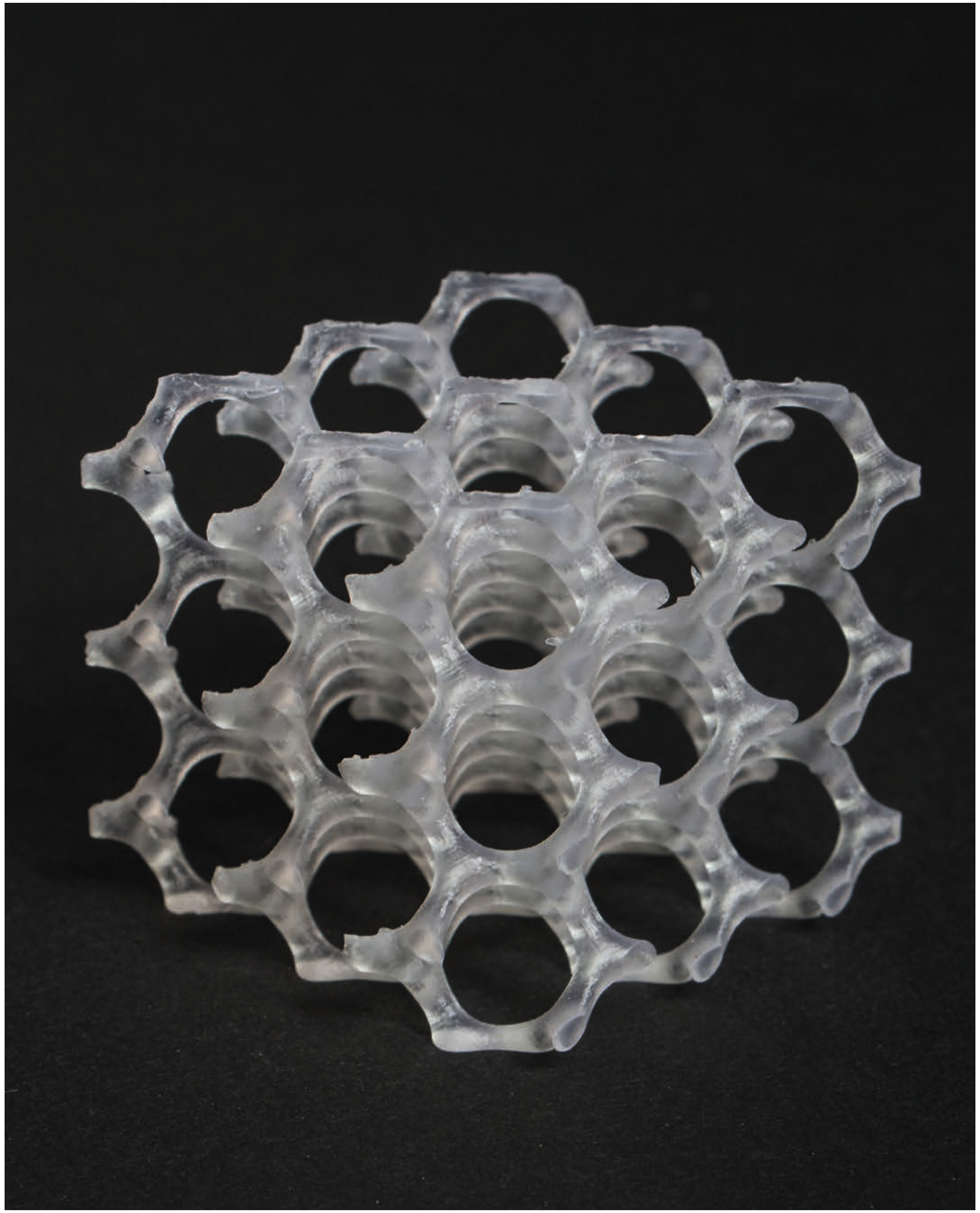
Rothen-Rutishauser has already begun a dialog with interested parties, with the objective to designate PIs or senior researchers who will serve as "EO Envoys" at their respective departments and assist with the implementation of EO actions. "The envoys will mirror the role of the Faculty Delegate of the NCCR at their departments, and regular meetings of the envoys, including with the person responsible for the Home Institution's EO office, are foreseen," she adds.

At first, these efforts will focus on the roundtable discussions on career development and daycare subsidization, since these activities have been judged positively by all participants. Rothen-Rutishauser points out that "the support of the Home Institution, which will subsidize two fulltime slots at the University of Fribourg's daycare center for the members of the participating departments, has been instrumental to the launch of the EO Envoys Program." The access of the departments to the daycare slots will however be contingent on their commitment to include this activity in their own department budget after the startup phase.

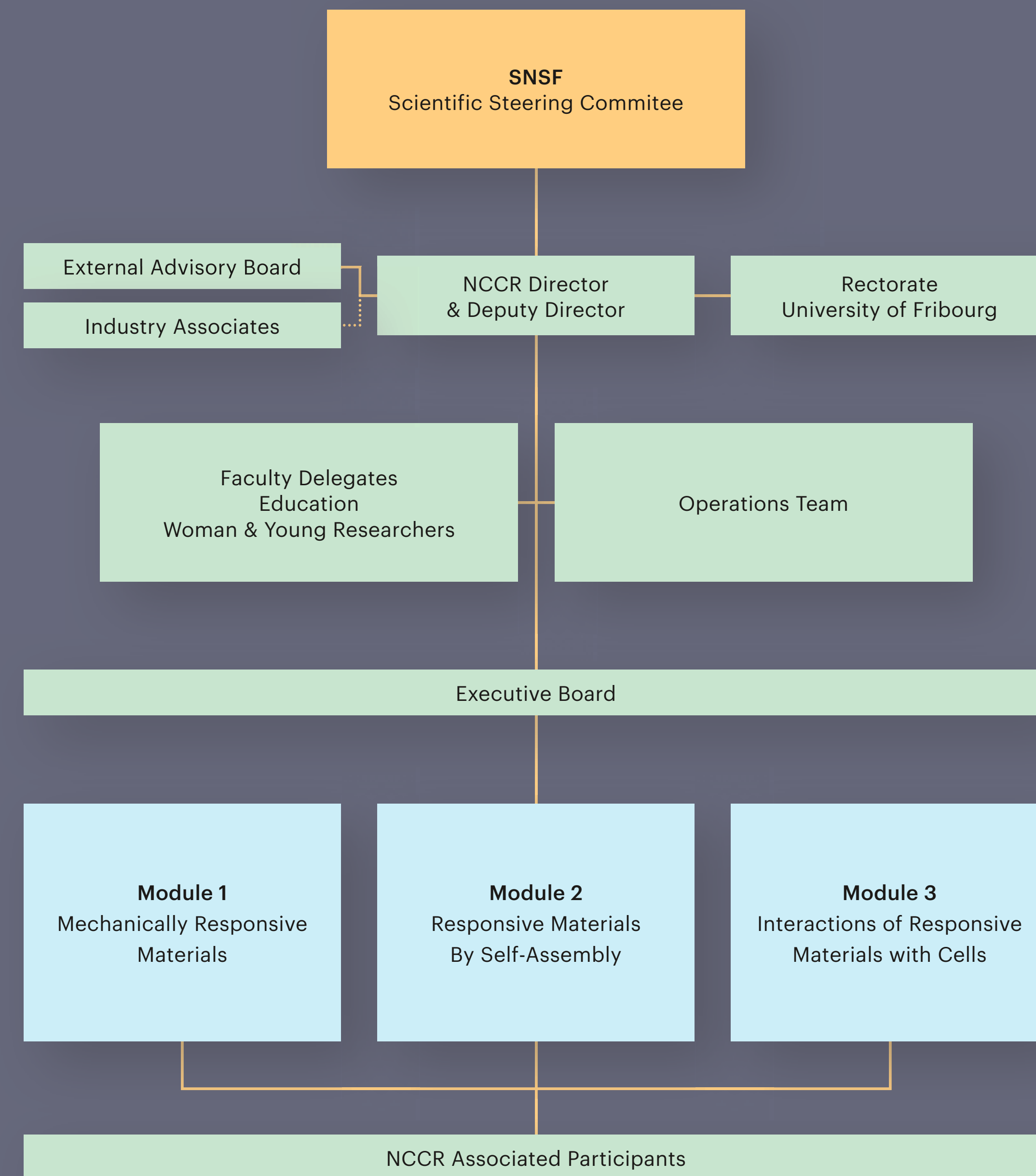
Other activities such as grant writing support and personal coaching of talented researchers will also be considered by the EO envoys, depending on the needs of the researchers in their departments. The support of young researcher sessions at national and international conferences was also successfully launched at the 2018 Nanotoxicology conference in Neuss, Germany. More than 70 participants joined the session co-led by Rothen-Rutishauser and Dr. Cordula Hirsch from Empa, with four young female speakers covering different aspects of nanoscience.

The coming years are thus expected to see the development and multiplication of EO activities at different levels under the leadership of the NCCR Bio-Inspired Materials.





Organization Phase I



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

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Executive board

- Prof. Christoph Weder (AMI)
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- Prof. Michal Borkovec (UniGE)
  Leader Module 1
- Prof. Frank Scheffold (UniFR)
  Leader Module 2
- Prof. Alke Fink (AMI/UniFR)
  Co-leader Module 3
- Prof. Barbara Rothen-Rutishauser (AMI)
  Faculty Delegate for Women and Young Researchers, co-leader Module 3
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- Dr. Lucas Montero
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- Dr. Eliav Haskal
  Knowledge Transfer and Innovation manager

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  (Adolphe Merkle Institute, UniFR)

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- Prof. Andreas Zumbühl (Department of Chemistry, UniFR)

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- Dr. Lucas Montero, Scientific coordinator (since 01.07.2017)
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- Dr. Frédéric Pont, Grant writer (since 15.05.2018)
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- Dr. Milad Radiom, Postdoctoral researcher
- Dr. Alexander Smith, Postdoctoral researcher
- Olivier Vassalli, Laboratory technician

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- Julia Wagner, Doctoral student

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- Dr. Luis Salvador Froufe Pérez, Postdoctoral researcher
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- Aristotelis Kamtsikakis, Doctoral student
- Marc Karman, Doctoral student
- Laura Neumann, Doctoral student
- Anita Roulin, Laboratory technician
- Dr. Stephen Schrettl, Postdoctoral researcher

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- Frederik Neuhaus, Doctoral student
- Etienne Stalder, Doctoral student
- Radu Tanasescu, Doctoral student

Support staff

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

Alumni

- Lauriane Alison (Doctoral student, Studart group) 2017–2017
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- Susanne Drechsler (Doctoral student, Kilbinger group) 2014–2017
- Matteo Gasbarri (Doctoral student, Stellacci group) 2017–2017
- Madeleine Grossman (Doctoral student, Studart group) 2014–2017
- Dr. Nelly Hérault (Postdoctoral researcher, Fromm group) 2015–2018
- Sandra Hocevar (Doctoral student, Bourquin group) 2017–2017
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- Radu Tanasescu (Doctoral student, Zumbühl group) 2015–2017
- Dr. Jelena Zaric (Postdoctoral researcher, Rüegg group) 2017–2017

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- Liam Anderson (Durham University)
- Amber Barron (University of Utah)
- Cheryl Chang (Dartmouth College)
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- Marcus Davis (Clemson University)
- Emily Dickens (Case Western Reserve University)
- Ashley Djuhadi (Case Western Reserve University)
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- Elizabeth Hopper (Durham University)
- Seth Meade (Durham University)
- Laura Pascual (Durham University)
- Seth Price (Durham University)
- Kunal Rath (Case Western Reserve University)
- Ashley Rein (Durham University)
- Eva Stefanovska (University Ss. Cyril and Methodius)
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- 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 and eliminate 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
15. Controlled activation of cancer-associated immune cells by stimuli-responsive nanoparticles

Publications

Module 1

Abram, S.-L.; Gagnon, J.; Priebe, M.; Hérault, N.; Fromm, K.M. Ag nanoencapsulation for antimicrobial applications, Chimia, 2018, 72, 249.

Alison, L.; Demirörs, A. F.; Tervoort, E.; Teleki, A.; Vermant, J.; Studart, A. R. Emulsions stabilized by chitosan-modified silica nanoparticles: pH control of structure-property relations, Langmuir, 2018, 34, 6147-6160.

Ayer, M. A.; Schrettl, S.; Balog, S.; Simon, Y. C.; Weder, C. Light-responsive azo-containing organogels, Soft Matter, 2017, 13, 4017-4023.

Badoux, M.; Drechsler, S.; Pal, S.; Kilbinger, A.F.M. Facile synthesis of a high molecular weight amphiphilic aramid–ROMP bock copolymer, Macromolecules, 2017, 50, 9307-9314.

Badoux, M.; Kilbinger, A.F.M. Synthesis of high molecular weight poly(p-benzamide)s, Macromolecules, 2017, 50, 4188-4197.

Brog, J.-P.; Crochet, A.; Seydoux, J.; Clift, M.J.D.; Baichette, B.; Maharajan, S.; Barosova, H.; Brodard, P.; Spodaryk, M.; Züttel, A.; Rothen-Rutishauser, B.; Kwon, N.-H.; Fromm; K.M. Characteristics and properties of nano-LiCoO2 synthesized by pre-organized single source precursors: Li-ion diffusivity, electrochemistry and biological assessment, J. Nanobiotechnol., 2017, 15, 58.

Calvino, C.; Guha, A.; Weder, C.; Schrettl, S. Self-calibrating mechanochromic fluorescent polymers based on encapsulated excimer-forming dyes, Adv. Mater., 2018, 30, 1704603.

Calvino, C.; Piechowicz, M.; Rowan, S.; Schrettl, S.; Weder, C. A versatile colorimetric probe based on thiosemicarbazide-amine proton transfer, Chem. - A Eur. J., 2018, 24, 7369-7373.

Chabert, V.; Hologne, M.; Sénèque, O.; Crochet, A.; Walker, O.; Fromm, K. M. Model peptide studies of Ag+ binding sites from the silver resistance protein SilE, Chem. Commun., 2017, 53, 6105-6108.

Demirors, A.; Akan, M. T.; Poloni, E.; Studart, A. R. Active Cargo Transport with Janus Colloidal Shuttles using Electric and Magnetic Fields, Soft Matter, 2018, 14, 4741-4749.

Gagnon, J.; Caruso, R. A.; Fromm, K. M. Embedding CeO_2 nanocontainers in a TiO_2 coating on glass surfaces, AIMS Bioeng., 2017, 4, 171-178.

Herault, N.; Fromm, K. M. Influence of the sacrificial polystyrene removal pathway on the TiO_2 nanocapsule structure, Helv. Chim. Acta, 2017, 100, e1700014.

Herbert, K. M.; Schrettl, S.; Rowan, S. J.; Weder, C. 50th Anniversary perspective: Solid-state multistimuli, multiresponsive polymeric materials, Macromolecules, 2017, 50, 8845-8870.

Imato, K.; Natterodt, J.; Sapkota, J.; Goseki, R.; Weder, C.; Takahara, A.; Otsuka, H. Dynamic covalent diarylbibenzofuranone-modified nanocellulose: mechanochromic behaviour and application in self-healing polymer composites, Polym. Chem., 2017, 8, 2115-2122.

Kozhuharov, S.; Radiom, M.; Maroni, P.; Borkovec, M. Persistence length of poly(vinyl amine): Quantitative image analysis versus single molecule force response, Macromolecules, 2018, 51, 3632–3639.

Lavrenova, A.; Balkenende, D.W.R.; Sagara, Y.; Schrettl, S.; Simon Y. C.; Weder C. Mechano- and thermoresponsive photoluminescent supramolecular polymer, J. Am. Chem. Soc., 2017, 139, 4302-4305.

Mase, K.; Sasaki, Y.; Sagara, Y.; Tamaoki, N.; Weder, C.; Yanai, N.; Kimizuka, N. Stimuli-responsive dual-color photon upconversion: An S-T absorption sensitizer in a soft luminescent cyclophane, Angew. Chem. Int. Ed., 2018, 57, 2806-2810.

Montero de Espinosa, L.; Meesorn, W.; Moatsou, D.; Weder, C. Bioinspired polymer systems with stimuli-responsive mechanical properties, Chem. Rev., 2017, 117, 12851-12892.

Moore, D. G.; Brignoli, J.V.A.; Rühs, P. A.; Studart, A. R. Functional microcapsules with hybrid shells made via sol–gel reaction within double emulsions, Langmuir, 2017, 33, 9007-9017.

Moore, D. G.; Brignoli, J.V.A.; Rühs, P. A.; Studart, A. R. Functional microcapsules with hybrid shells made via sol–gel reaction within double emulsions, Langmuir, 2017, 33, 9007-9017.

Pal, S.; Lucarini, F.; Ruggi, A.; Kilbinger, A.F.M. Functional metathesis catalyst through ring closing enyne metathesis: One pot protocol for living heterotelechelic polymers, J. Am. Chem. Soc., 2018, 140, 3181-3185.

Radiom, M.; Borkovec, M. Influence of ligand-receptor interactions on force-extension behavior within the freely jointed chain model, Phys. Rev. E, 2017, 96, 062501.

Radiom, M.; Kozhuharov, S.; Kong, P.; di Giannantonio, M.; Ayer, M.; Maroni, P.; Kilbinger, A. M.; Fromm, K.; Weder, C.; Borkovec, M. Quantitative nano-characterization of polymers using atomic force microscopy, Chimia, 2017, 71, 195-198.

Radiom, M.; Maroni, P.; Borkovec, M. Influence of solvent quality on the force response of individual poly(styrene) polymer chains, ACS Macro Lett., 2017, 6, 1052-1055.

Radiom, M.; Maroni, P.; Wesolowski, T. A. Size extensivity of elastic properties of alkane fragments, J. Mol. Model., 2018, 24, 36.

Rifaie-Graham, O.; Apebende, E. A.; Bast, L. K.; Bruns, N. Self reporting fiber reinforced composites that mimic the ability of biological materials to sense and report damage, Adv. Mater., 2018, 30, 1705483.

Sagara, Y.; Karman, M.; Verde-Sesto, E.; Matsuo, K.; Kim, Y.; Tamaoki, N.; Weder, C. Rotaxanes as Mechanochromic Fluorescent Force Transducers in Polymers, J. Am. Chem. Soc., 2018, 140, 1584-1587.

Sagara, Y.; Weder, C.; Tamaoki, N. Asymmetric cyclophanes permit access to supercooled nematic liquid crystals with stimulus-responsive luminescence, Chem. Mater., 2017, 29, 6145-6152.

Schaffner, M.; Faber, J. A.; Pianegonda, L.; Rühs, P. A.; Coulter, F.; Studart, A. R. 3D printing of robotic soft actuators with programmable bioinspired architectures, Nat. Commun., 2018, 9, 878.

Ulrich S.; Hemmer, J. R.; Page, Z.A.; Dolinski, N. D.; Rifaie-Graham O.; Bruns, N.; Hawker, C. J.; Boesel, L. F.; Read de Alaniz, J. Visible light-responsive DASA-polymer conjugates, ACS Macro Lett., 2017, 6, 738-742.

Vasylevskyi, S. I.; Kracht, S.; Corcosa, P.; Fromm, K. M.; Giese, B.; Füeg, M. Formation of silver nanoparticles by electron transfer in peptides and c-cytochromes, Angew. Chem. Int. Ed., 2017, 56, 5926-5930.

Zimmermann, S.; Balkenende, D.; Lavrenova, A.; Weder, C.; Brugger, J. Nanopatterning of a stimuli-responsive fluorescent supramolecular polymer by thermal scanning probe lithography, ACS Appl. Mater. Interfaces, 2017, 9, 41454–41461.

Module 2

Braibanti, M.; Kim, H. S.; Şenbil, N.; Pagenkopp, M. J.; Mason, T. G.; Scheffold, F. The liquid-glass-jamming transition in disordered ionic nanoemulsions, Sci. Rep., 2017, 7, 13879.

Conley, G.M.; Aebischer, P.; Nöjd, S.; Schurtenberger, P.; Scheffold, F. Jamming and overpacking fuzzy microgels: Deformation, interpenetration, and compression, Sci. Adv., 2017, 3, e1700969.

Diederich, V.E.D.; Villiger, T.; Storti, G.; Lattuada, M. Modeling of the degradation of poly(ethylene glycol)-co-(lactic acid)-dimethacrylate hydrogels, Macromolecules, 2017, 50, 5527-5538.

Dehmel, R.; Baumberg, J. J.; Steiner, U.; Wilts, B. D. Spectrally resolved surface plasmon resonance dispersion using half-ball optics, Appl. Phys. Lett., 2017, 111, 201102.

Dehmel, R.; Dolan, J. A.; Gu, Y.; Wiesner, U.; Wilkinson, T. D.; Baumberg, J. J.; Steiner, U.; Wilts, B. D.; Gunkel, I. Optical imaging of large gyroid grains in block copolymer templates by confined crystallization, Macromolecules, 2017, 50, 6255-6262.

Froufe-Pérez, L. S.; Engel, M.; Sáenz, J. J.; Scheffold, F. Band gap formation and Anderson localization in disordered photonic materials with structural correlations, Proc. Nat. Acad. Sci. USA, 2017, 114, 9570.

Hasanabadi, N.; Nazockdast, H.; Balog, S.; Lattuada, M. Rheological characterization of nanostructured material based on polystyrene-b-poly(ethylene-butylene)-b-polystyrene (SEBS) block copolymer: Effect of block copolymer composition and nanoparticle geometry, Compos. Sci. Technol., 2017, 149, 192-206.

Hasanabadi, N.; Nazockdast, H.; Gajewska, B.; Balog, S.; Gunkel, I.; Bruns, N.; Lattuada, M. Structural behavior of cylindrical polystyrene-block-poly(ethylene-butylene)-block-polystyrene (SEBS) triblock copolymer containing MWCNTs: On the influence of nanoparticle surface modification, Macromol. Chem. Phys., 2017, 218, 1700231.

Isapour, G.; Lattuada, M. Bioinspired stimuli responsive color changing systems, Adv. Mater., 2018, 30, 1707069.

Johansen, V. E.; Catón, L.; Hamidjaja, R.; Oosterink, E.; Wilts, B. D.; Rasmussen, T. S.; Sherlock, M. M.; Ingham, C. J.; Vignolini, S. Genetic manipulation of structural color in bacterial colonies, Proc. Nat. Acad. Sci. USA, 2018, 115, 2652-2657.

McDonald, L. T.; Finlayson, E. D.; Wilts, B. D.; Vukusic, P. Circularly polarized reflection from the scarab beetle Chalcothea smaragdina: Light scattering by a dual photonic structure, Interface Focus, 2017, 7, 20160129.

Moyroud, E.; Wenzel, T.; Middleton, R.; Rudall, P. J.; Banks, H.; Reed, A.; Meller, G.; Killoran, P.; Westwood, M. M.; Steiner, U.; Vignolini, S.; Glover, B. J. Disorder in convergent floral nanostructures enhances signalling to bees, Nature, 2017, 550, 469.

Muller, N.; Haberko, J.; Marichy, C.; Scheffold, F. Photonic hyperuniform networks obtained by silicon double inversion of polymer templates, Optica, 2017, 4, 361-366.

Neuhaus, F.; Mueller, D.; Tanasescu, R.; Balog, S.; Ishikawa, T.; Brezesinski, G.; Zumbuehl, A. Vesicle origami: Cuboid phospholipid vesicles formed by template free self assembly, Angew. Chem. Int. Ed., 2017, 56, 6515-6518.

Neuhaus, F.; Mueller, D.; Tanasescu, R.; Balog, S.; Ishikawa, T.; Brezesinski, G.; Zumbuehl, A., Synthesis and biophysical characterization of an odd-numbered 1,3-diamidophospholipid, Langmuir, 2018, 34, 3215-3220.

Stavenga, D. G.; Leertouwer, H. L.; Wilts, B. D. Magnificent magpie colours by feathers with layers of hollow melanosomes, J. Exp. Biol., 2017, 221, jeb.174656.

Stavenga, D. G.; van der Kooi, C. J.; Wilts, B. D. Structural coloured feathers of mallards act by simple multilayer photonics, J. R. Soc. Interface, 2017, 14, 20170407.

Stalder, E.; Zumbuehl, A. Liposome-containing mechanoresponsive hydrogels, Macromol. Mater. Eng., 2017, 302, 1600549.

Wilts, B. D.; Apeleo-Zubiri, B.; Klatt, M. A.; Butz, B.; Fischer, M. G.; Kelly, S. T.; Spieker, E.; Steiner, U.; Schröder-Turk, G. E. Butterfly gyroid nanostructures as a time-frozen glimpse of intracellular membrane development, Sci. Adv., 2017, 3, e1603119.

Wilts, B. D.; Dumanli, A. G.; Middleton, R.; Vukusic, P.; Vignolini, S. Chiral optics of helicoidal cellulose nanocrystal films, APL Photonics, 2017, 2, 040801.

Wilts, B. D.; Sheng, X.; Holler, M.; Diaz, A.; Guizar Sicairos, M.; Raabe, J.; 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, Adv. Mater., 2017, 30, 1702057.

Wilts, B. D.; Vey, A. J.; Briscoe, A. D.; Stavenga, D. G. Longwing (Heliconius) butterflies combine a restricted set of pigmentary and structural coloration mechanisms, BMC Evol Biol., 2017, 17, 226.

Module 3

Balog S. Taylor dispersion of polydisperse nanoclusters and nanoparticles: Modeling, simulation, and analysis, Anal. Chem., 2018, 90, 4258-4262.

Balog, S.; Urban, D. A.; Milosevic, A. M.; Crippa, F.; Rothen-Rutishauser, B.; Petri-Fink, A. Taylor dispersion of nanoparticles, J. Nanopart. Res., 2017, 19, 287.

Bossert, D.; Crippa, F.; Petri-Fink, A.; Balog, S. Hypothesis Test of the photon count distribution for dust discrimination in dynamic light scattering, Anal. Chem., 2018, 90, 3656-3660.

Bossert, D.; Natterodt, J.; Urban, D. A.; Weder, C.; Petri-Fink, A.; Balog, S. Speckle-visibility spectroscopy of depolarized dynamic light scattering, J. Phys. Chem. B, 2017, 121, 7999.

Bourquin, J.; Milosevic, A.; Hauser, D.; Lehner, R.; Blank, F.; Petri-Fink, A.; Rothen-Rutishauser, B. Biodistribution, clearance, and long-term fate of clinically relevant nanomaterials, Adv. Mater., 2018, 30, 1704307.

Cagno, V.; Andreozzi, P.; D'Alicarnasso, M.; Silva, P. J.; Müller, M.; Galloux, M.; Le Goffic, R.; Jones, S. T.; Vallino, M.; Hodek, J.; Weber, J.; Sen, S.; Janeçek, E. R.; Bekdemir, A.; Sanavio, B.; Martinelli, C.; Donalisio, M.; Rameix Welti, M. A.; 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, Nat. Mater., 2018, 17, 195-203.

Crippa, F.; Thorén, P.-A. Forchheimer, D.; Borgani, R.; Rothen-Rutishauser, B.; Petri-Fink, A.; Haviland D. B. Probing nano-scale viscoelastic response in air and in liquid with dynamic atomic force microscopy, Soft Matter, 2018, 14, 3998-4006.

Drasler, B.; Sayre, P.; Steinhäuser, K. G.; Petri-Fink, A.; Rothen-Rutishauser, B. In vitro approaches to assess the hazard of nanomaterials, Nanoimpact, 2017, 8, 99.

Drasler, B.; Vanhecke, D.; Rodriguez-Lorenzo, L.; Petri-Fink, A.; Rothen-Rutishauser, B. Quantifying nanoparticle cellular uptake: Which method is best?, Nanomedicine (Lond.), 2017, 12, 1095.

Durantie, E.; Vanhecke, D.; Rodriguez-Lorenzo, L.; Delhaes, F.; Balog, S.; Septiadi, D.; Bourquin, J.; Petri-Fink, A.; Rothen-Rutishauser, B. Biodistribution of single and aggregated gold nanoparticles exposed to the human lung epithelial tissue barrier at the air-liquid interface, Part. Fibre Toxicol., 2017, 14, 49.

Ebersold, M. M.; Petrovic, M.; Fong, W.-K.; Bonvin, D.; Hofmann, H.; Miloševic, I. Hexosomes with undecylenic acid efficient against Candida albicans, Nanomaterials, 2018, 8, 91.

Fennouri, A.; Mayer, S. F.; Schroeder, T. B.; Mayer, M. Single channel planar lipid bilayer recordings of the melittin variant MelP5, BBA Biomembranes , 2017, 1859, 2051-2057.

Kinnear, C.; Moore, T. L.; Rodriguez Lorenzo, L.; Rothen-Rutishauser, B.; Petri-Fink, A. Form follows function: Nanoparticle shape and its implications for nanomedicine, Chem. Rev., 2017, 117, 11476.

Lemal, P.; Geers, C.; Rothen-Rutishauser, B.; Lattuada, M.; Petri-Fink, A. Measuring the heating power of magnetic nanoparticles: An overview of currently used methods, Mater. Today: Proceedings, 2017, 4, S107.

Lucke, M.; Mottas, I.; Herbst, T.; Hotz, C.; Römer, L.; Schierling, M.; Herold, H. M.; Slotta, U.; Spinetti, T.; Scheibel, T.; Winter, G.; Bourquin, C.; Engert, J. Engineered hybrid spider silk particles as delivery system for peptide vaccines, Biomaterials, 2018, 172, 105-115.

Milosevic, A.; 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, Angew. Chem. Int. Ed., 2017, 56, 13382-13386.

Monnier, C. A.; Crippa, F.; Geers, C.; Knapp, E.; Rothen-Rutishauser, B.; Bonmarin, M.; Lattuada, M.; Petri-Fink, A. Lock-in thermography as an analytical tool for magnetic nanoparticles: Measuring heating power and magnetic fields, J. Phys. Chem. C, 2017, 121, 27164-27175.

Moore, T.; Hauser, D.; Gruber, T.; Rothen-Rutishauser, B.; Lattuada, M.; Petri-Fink, A.; Lyck, R. Cellular shuttles: Monocytes/macrophages exhibit transendothelial transport of nanoparticles under physiological flow, ACS Appl. Mater. Interfaces, 2017, 9, 18501.

Schroeder, T.B.H.; Houghtaling, J.; Wilts, B. D.; Mayer, M. It's not a bug, it's a feature: Functional materials in insects, Adv. Mat., 2018, 30, 1705322.

Secondini, C.; Coquoz, O.; Spagnuolo, L.; Spinetti, T.; Peyvandi, S.; Ciarloni, L.; Botta, F.; Bourquin, C.; Rüegg, C. Arginase inhibition suppresses lung metastasis in the 4T1 breast cancer model independently of the immunomodulatory and anti-metastatic effects of VEGFR-2 blockade, Oncoimmunology, 2017, 20, e1316437.

Septiadi, D.; Crippa, F.; Moore, T. L.; Rothen-Rutishauser, B.; Petri-Fink, A. Nanoparticle–cell interaction: A cell mechanics perspective, Adv. Mater., 2018, 30, 1704463.

Vanhecke, D.; Kuhn, D. A.; Jimenez de Aberasturi, D.; Balog, S.; Milosevic, A.; Urban, D.; Peckys, D.; de Jonge, N.; Parak, W. J.; Petri-Fink, A.; Rothen-Rutishauser, B. Involvement of two uptake mechanisms of gold and iron oxide nanoparticles in a co-exposure scenario using mouse macrophages, Beilstein J. Nanotechnol., 2017, 8, 2396-2409.

Vanhecke, D.; Rodriguez-Lorenzo, L.; Kinnear, C.; Durantie, E.; Rothen-Rutishauser, B.; Petri-Fink, A. Assumption-free morphological quantification of single anisotropic nanoparticles and aggregates, Nanoscale, 2017, 9, 4918.

Widmer, J.; Thauvin, C.; Mottas, I.; Nguyen, V.; Delie, F.; Allémann, E.; Bourquin, C. Polymer-based nanoparticles loaded with a TLR7 ligand to target the lymph node for immunostimulation, Int. J. Pharm., 2018, 535, 444.

5

Patent applications

Gender balance

More than half of the NCCR Ph.D. students are women (53%)

43% of NCCR staff were women during Phase I

170 papers

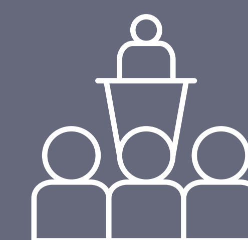
155 original contributions and 15 reviews

84

poster presentations

127 oral presentations at conferences

including 58 keynote and plenary lectures at international conferences



260

children

participated in outreach activities

113

cooperation projects

with external partners (26 with industry, 80 with research institutions)

Note: All figures between June 1, 2014, and February 28, 2018

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. Christiane Löwe	Unintentional bias	University of Zurich, Switzerland	13 June 2017
Dr. Andreas Herrmann	Photolabile Profragrances – from Organic Chemistry to Material Sciences	Firmenich SA, Switzerland	26 September 2017
Prof. Cordt Zollfrank	Biotemplating as a route to advanced structural and functional materials	Technical University of Munich, Straubing, Germany	10 October 2017
Prof. Andreas Walther	Static & Dynamic Bioinspired Self-Assembled Material Systems	Albert Ludwigs University of Freiburg, Freiburg, Germany	07 November 2017
Prof. Korin Wheeler	Insights into biomolecular interactions of engineered nanomaterials	Santa Clara University, California, US	29 November 2017
Dr. Erik Thiele	R&D in a global science company: How things work	DuPont Performance Materials, Geneva, Switzerland	23 January 2018
Prof. Monika Ritsch-Marte	How SLM-based wavefront shaping impacts Biophotonics, from holographic optical micro-manipulation to programmable microscopy	Medical University of Innsbruck, Innsbruck, Austria	23 May 2018
Prof. Niels Holten-Andersen	Bio-inspired metal-coordination crosslinking: Easy access to broad dynamics when engineering polymer gel mechanics	MIT, Cambridge, MA, USA	29 May 2018

Impressum

Editorial: Christoph Weder / Curzio Rüegg / Lucas Montero / Scott Capper **Text:** Scott Capper / Annika Weder / Christoph Weder / Curzio Rüegg / Eliav Haskal **Proofreading:** Annika Weder **Photos:** Page 2, Marc Karman / Page 4, Aldo Ellena / Pages 6, 7 BM PHOTOS / Page 9, SUNMIL/EPFL / Pages 10, Charly Rappo / Pages 12, 17, 19, 21, 23, 25, 27, 28, 38, 46, 47 Shutterstock / Pages 30, 34, Marion Savoy / Page 30, Christopher Schaller / Page 33, NCCR Bio-Inspired Materials / Page 33, Eric Dufresne / Page 37, DTS / Page 35, Laura Neumann / Page 60, Johannes Kaufmann / all other pictures, Scott Capper **Additional graphics:** Created by arejoenah from the Noun Project **Graphic design:** Grafikraum, Manuel Haefliger, Bern **Printer:** Imprimerie Saint-Paul, Fribourg

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