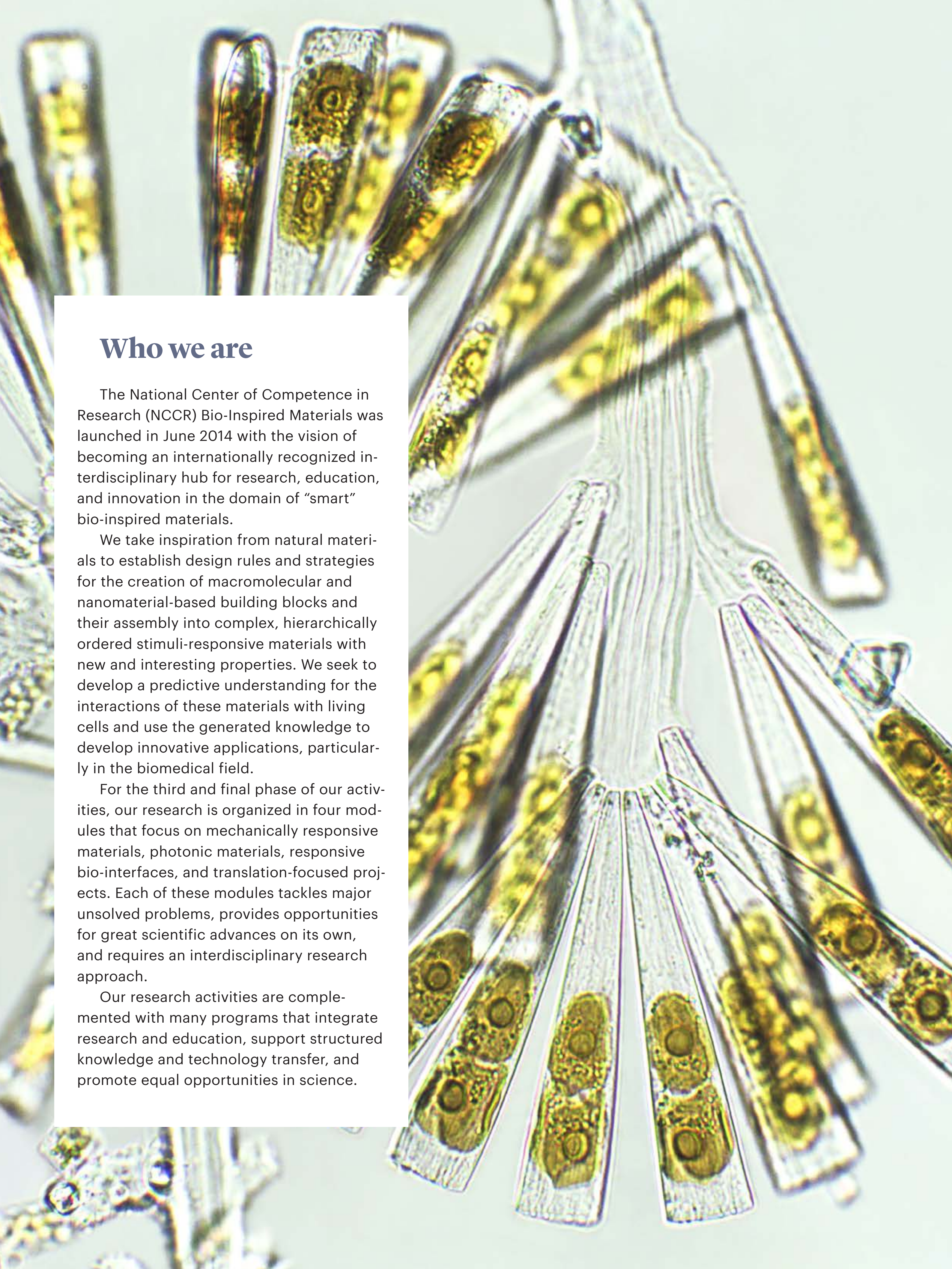
Activities report 2023–2024

National Center of Competence in Research Bio-Inspired Materials

Swiss National Science Foundation

BIO-INSPIRED MATERIALS
NATIONAL CENTER OF COMPETENCE IN RESEARCH



Who we are

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

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

For the third and final phase of our activities, our research is organized in four modules that focus on mechanically responsive materials, photonic materials, responsive bio-interfaces, and translation-focused projects. 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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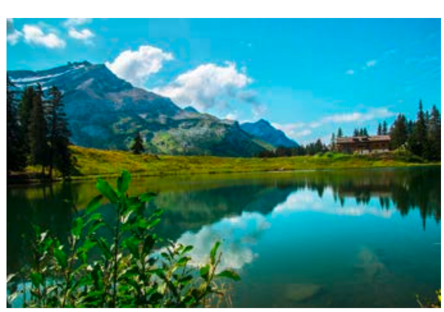


Content

Message from the directors

Stabilizing our research for the future

The NCCR Bio-inspired Materials has reached the halfway point of its third and final funding phase, with a reorganization of its research program underway.

Module 3 was renamed "Bio-Interfaces Across Scales," and two projects were terminated, their resources redistributed to other initiatives within Modules 1 and 3, and two other projects refocused. Furthermore, two projects were strengthened with postdoctoral positions through the WINS Postdocs Program, which involved an internal call and external evaluation. The Center's collaborative spirit continues to grow. In fact, 28% of the publications involved up to three NCCR research groups. As part of this expanding network, we are pleased to announce that Prof. Alessandro Ianiro, a former senior researcher of our NCCR, has been appointed Assistant Professor at KU Leuven. He has recently integrated our Center as Associate PI, further enriching our expertise in soft and complex materials.

The NCCR continues to play a leading role in the biannual Gordon Research Conference on Bioinspired Materials, held in Switzerland. This conference enhances Switzerland's visibility in the field, and in 2024, the conference was chaired by NCCR PI Christoph Weder. In 2026, the conference will be led by NCCR Director Ullrich Steiner, which demonstrates our continued strong sponsorship and support of this flagship event.

The Adolphe Merkle Institute is establishing a new chair in Food Science and Technology, a field strongly connected to bio-inspired research and already represented in our Center, in alignment with its long-standing goals. This new position will support the region's strategic aim to become a hub in the agri-food sector. We are also in discussions with the University of Fribourg and other key stakeholders to explore pathways for stabilizing the NCCR's future beyond May 2026.

Our Center also spearheaded several impactful activities beyond research. The URI Program is one of our most successful educational activities. Since its launch in 2015, it has attracted 146 international undergraduate students from 48 universities across 14 countries. The WINS Fellowship has expanded, welcoming four new fellows, two of whom are fully funded by the University of Fribourg. This is a testament to the NCCR's Home Institution's unwavering commitment to gender equality. Our Center also hosted the "Falling Walls Lab Fribourg," a high-caliber pitch competition where PhD students and postdocs present transformative ideas to a panel of innovation experts. One of the winner's, NCCR alumna Ivana Domljanovic, was selected to participate in the World Final in Berlin.

This report showcases the cutting-edge initiatives and activities that propel the NCCR Bio-inspired Materials forward. It features research highlights, new perspectives for cancer treatment, and international student exchanges. We thank you for your interest in our NCCR and look forward to future engagement and collaboration.

Ullrich Steiner & Esther Amstad
Directors NCCR Bio-Inspired Materials

Research

What we do

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

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

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

Colorful

Beetle color secrets to create vibrant hues

Adding a natural pigment to certain materials allowed researchers to develop bright, vivid colors more efficiently – an innovation that could find various applications.

As the world increasingly focuses on sustainability, developing efficient and eco-friendly methods for producing color is essential. Traditional techniques often rely on chemical pigments and materials that can harm the environment. Now, NCCR Bio-Inspired Materials researchers have combined structural color techniques with natural pigments to produce vibrant colors. This approach may enable more sustainable color production for paints and other applications.

"The promise of structural color is that one day, we would be able to make all the colors out of just a few materials, and that would produce a lot less chemical waste and greatly facilitate recycling," says NCCR PI Eric Dufresne, Professor of Materials Science and Engineering at Cornell University in Ithaca, New York. What's more, he says, structural colors tend to be more stable compared to pigment-based colors, which can fade over time.

The inspiration for the project came from the observations of another NCCR researcher, Bodo Wilts, Professor of Chemistry and Physics of Materials at the University of Salzburg. Wilts previously noticed that the vibrant colors in a beetle didn't align with traditional color theories, which classify colors as either structural – emerging from the arrangement of nanostructures within a material – or based on chemical substances called pigments. This led the researchers to propose that combining structural and pigment-based methods could create even more intense colors. "Sometimes, one plus one equals three," Dufresne says.

> "All these organisms have to produce these crazy structures without a laboratory – they need to do this in the wild and they need to do it reliably."
>
> Prof. Eric Dufresne, Cornell University

For this study, Wilts and Dufresne teamed up with Frank Scheffold, Professor of Physics at the University of Fribourg. The team set out to build an artificial system to test Wilts' hypothesis and confirmed that merging structural color with pigments produced brighter colors using fewer materials.

In their experiments, the researchers used beta-carotene, the pigment responsible for carrots' color, alongside structural color techniques. They found that this combination allowed them

For new brighter colors, add for example the pigment responsible for carrots' hue to a color-generating structure

to achieve high brightness while significantly decreasing the number of material layers needed.

The researchers created a material made up of layers of polyvinyl alcohol and polystyrene, mixed with varying amounts of beta-carotene. By adding beta-carotene to the material, they increased the index of refraction, which is important for creating structural color. For example, to obtain 90% reflection efficiency, they required 31 layers without pigment; this number dropped to just 15 layers when beta-carotene was included.

This approach not only produced vivid colors but also did so with fewer resources, making it a more environmentally friendly option. However, Dufresne notes that while the pigment is plant-based, other materials in the system are derived from oil.

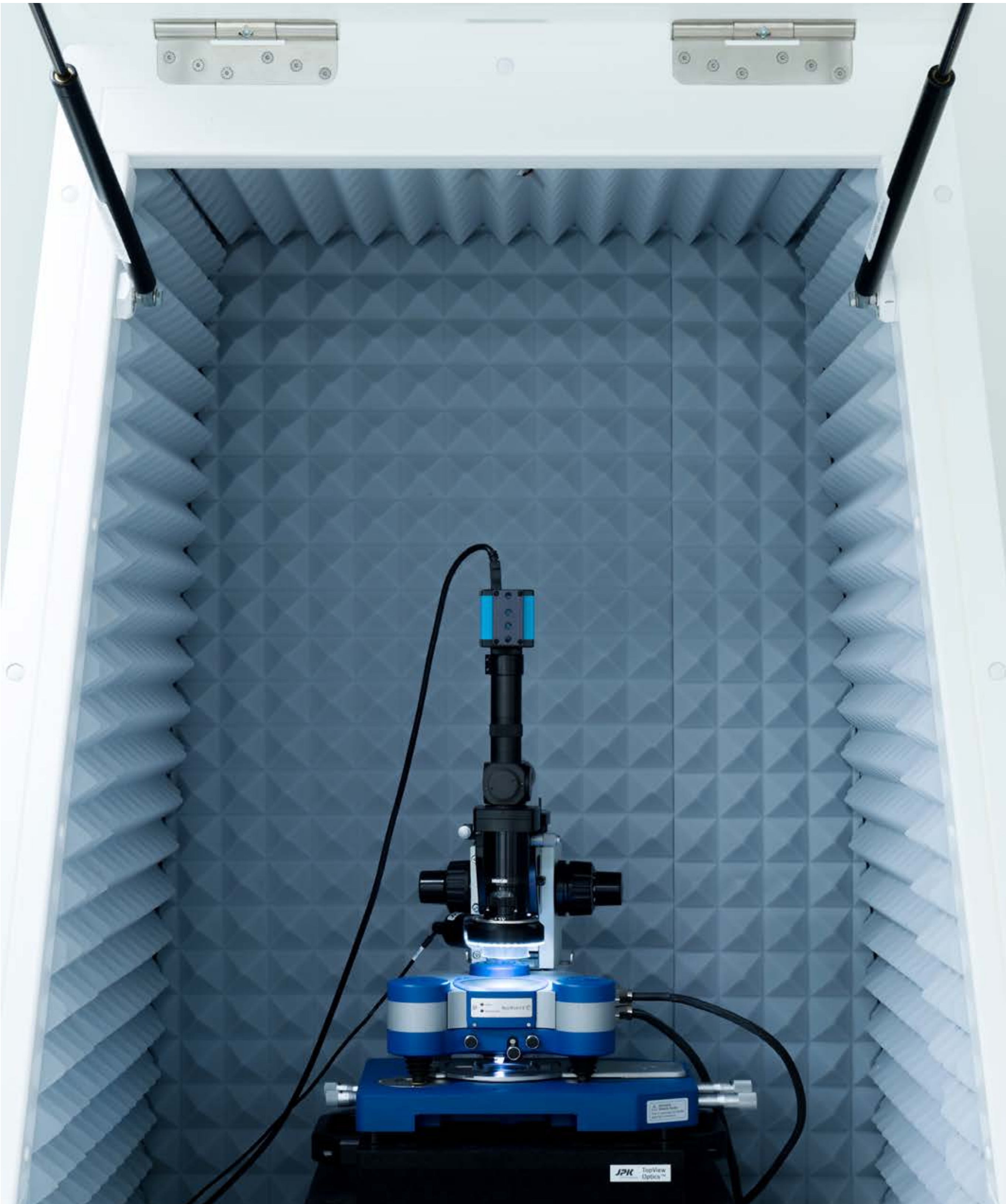
Adding beta-carotene to polystyrene also resulted in a broader range of colors, which included green and orange shades. The team published their findings in the journal *Soft Matter*.

Before this approach finds applications in the real world, more work is needed to integrate pigments into self-assembled materials for easier processing, Dufresne says. And although the method allows for bright colors such as orange and green, the capacity to create more colors remains limited, he adds.

For his part, Dufresne is focused on understanding the processes that enable organisms such as beetles and butterflies to create the nanostructures responsible for producing structural color. "All these organisms have to produce these crazy structures without a laboratory — they need to do this in the wild and they need to do it reliably," he says. "This is the thing that I find most fascinating."

Reference

Sai, T.; Froufe-Pérez, L. S.; Scheffold, F.; Wilts, B. D.; Dufresne, E. R. Structural Color from Pigment-Loaded Nanostructures. Soft Matter 2023, 19 (40), 7717–7723.



20

Research Projects

CHF 6.8 mill.

of funding including CHF 2.9 million from the SNSF

Partners

University of Fribourg (home institution), Federal Institutes of Technology Lausanne and Zürich, Cornell, TU Darmstadt, Paris-Lodron-University Salzburg, KU Leuven, CSEM, Empa

27

Research groups

at seven universities

3

national cooperation

projects with industry

2

industrial associates

2

Innosuisse projects

5

national and international conferences

supported by the NCCR Bio-Inspired Materials

Note: All figures between June 1, 2023 – May 31, 2024

3D printable

Innovative materials for soft robotics

Living organisms often store chemicals in tiny compartments, using particles and vesicles to maintain high concentrations of reagents. Inspired by nature's use of compartmentalization, NCCR Bio-Inspired Materials researchers set out to create materials that offer similar efficiency and adaptability – an approach that could find applications in soft robotics, rehabilitation devices, and more.

The team, led by NCCR PI Prof. Esther Amstad at the École Polytechnique Fédérale de Lausanne, initially focused on hydrogels. Hydrogels are water-rich materials that tend to dry out over time, making them unsuitable for robotics that are exposed to air. So, the researchers turned to elastomers, rubber-like materials that do not retain moisture. The challenge, however, was that elastomers lack the ability to locally control flexibility and stiffness, which is crucial for creating elastomer-based mechanical joints and moving robots.

To overcome this limitation, the team developed a unique method for turning elastomers into tiny microparticles. This process involves creating drops of elastomer ingredients in the form of an oil-in-water emulsion. When these droplets are exposed to UV light, a chemical reaction occurs, transforming them into solid microparticles. These particles can then be combined with additional elastomer precursors to create a paste that can be 3D printed. After printing, another UV-triggered reaction solidifies the material, forming a second network that links the microparticles together.

By adjusting the composition of the microparticles and the second elastomer network, it is possible to create materials that range from soft and flexible to stiff and strong. Unlike traditional elastomers, the mechanical properties of these materials – called Double Network Granular Elastomers (DNGEs) – can be changed at will. "We can locally vary mechanics, and this allows us to print materials that deform in predefined fashions," Amstad says.

> "We can locally vary mechanics, and this allows us to print matetrials that deform in predefined fashions."
>
> Prof. Esther Amstad

The mechanical properties of the new elastomer can be changed at will

DNGEs could be stretched up to 1000% without breaking, the team found. Different composition of the microparticles also resulted in varying degrees of stretchability and energy absorption. For example, when the researchers dropped a ball onto both a soft and a stiff DNGE, the soft version absorbed almost all of the ball's energy, while the stiff version made it rebound. The researchers published their findings in the journal *Advanced Materials*.

The potential applications for these materials are vast, including in soft robotics, wearable devices, and prosthetics such as mechanical joints that allow movement in certain directions while restricting unwanted motion, Amstad says.

She also notes that study first author Eva Baur, a PhD student in her lab, has undergone extensive training in entrepreneurship and is looking to launch a spin-off company to commercialize these innovative materials. The initiative, Amstad says, highlights the support Baur received from the broader NCCR Bio-Inspired Materials network, which provided her with diverse perspectives and encouragement throughout her doctoral studies.

Reference

Baur, E.; Tiberghien, B.; Amstad, E. 3D Printing of Double Network Granular Elastomers with Locally Varying Mechanical Properties. Advanced Materials 2024, 36 (23), 2313189.

AI detection

Studying protein clumps in neurodegenerative diseases

Neurodegenerative conditions such as Alzheimer's and Parkinson's disease are characterized by the buildup of misfolded proteins in the brain. Understanding whether and how these protein clumps contribute to disease is key for developing effective treatments, but traditional methods for studying these aggregates rely on fluorescent tags that can alter the proteins' natural behavior, which may lead to inaccurate results.

Now, NCCR Bio-Inspired Materials researchers have developed a method that uses artificial intelligence (AI) to detect protein aggregates in living cells without the need for fluorescent labels.

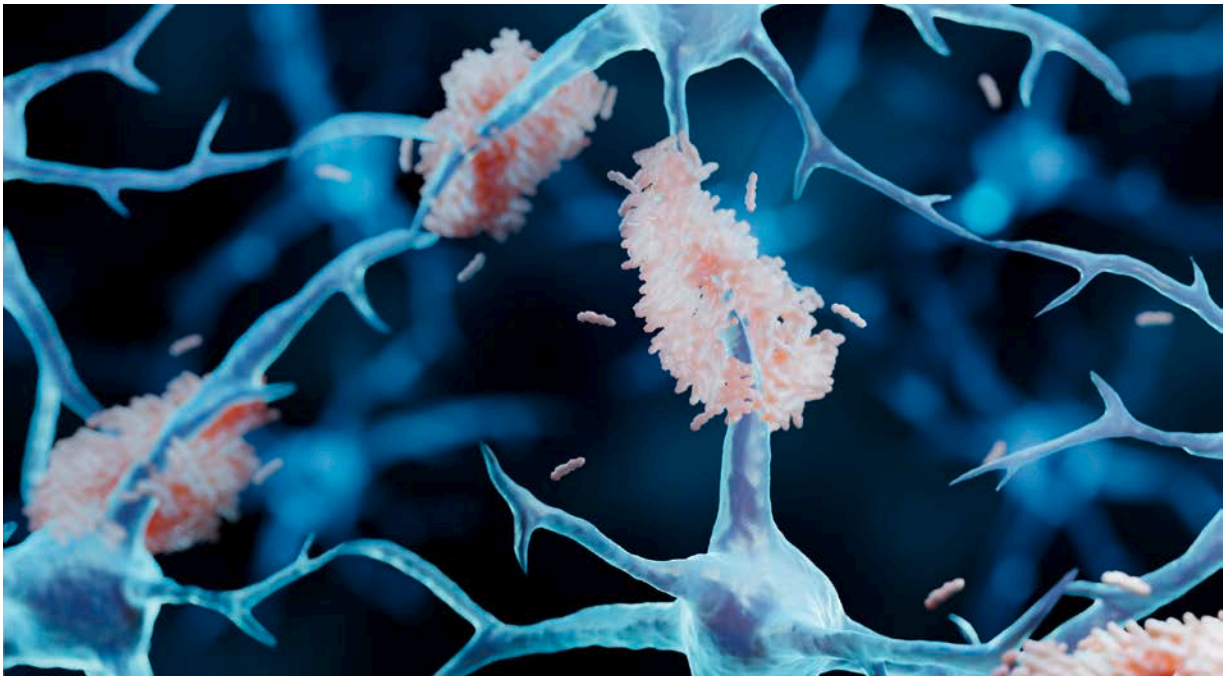
The approach allows for accurate, real-time measurements of protein aggregates, providing a better way to investigate the biological processes underlying neurodegenerative diseases. "We wanted to develop a tool to study biological processes as accurately as fluorescence tools allow us, but in a label-free manner," says NCCR PI and study senior author Aleksandra Radenovic, Professor of Biological Engineering at the École Polytechnique Fédérale de Lausanne.

The team draw inspiration from nature, Radenovic says, emphasizing that living organisms don't have artificial labels such as green fluorescent proteins. What's more, the researchers used neural networks, which work similarly to the human brain by mimicking the way neurons interact and learn from experience. This approach allows the neural network to improve its accuracy over time.

Radenovic and her team used cells that overexpress a mutant version of a protein that leads to the formation of aggregates that are observed in Huntington's disease – a neurodegenerative disorder that leads to movement, cognitive and psychiatric symptoms. Using a custom-built microscope, the team collected bright-field and fluorescence images of these cells.

> "Our approach has a 96% accuracy in detecting true aggregates, showing great promise for advancing research in neurodegenerative diseases."
>
> Khalid Ibrahim, PhD student

Then, the researchers trained a neural network that could accurately identify these aggregates in 2D images without fluorescent tags. This label-free method is a powerful tool for studying protein aggregation in living cells, says study lead author Khalid Ibrahim, a PhD student in Radenovic's lab.



Misfolded proteins in the brain are a characteristic of neurodegenerative diseases

"Our approach has a 96% accuracy in detecting true aggregates, showing great promise for advancing research in neurodegenerative diseases," he says.

The tool, which the researchers dubbed label-free identification of NDD-associated aggregates (LINA), was effective under varying conditions, including low light and different cell lines. LINA not only identified protein aggregates in living cells but could also track their growth over time, the researchers reported in *Nature Communications*.

Understanding the growth rate of these aggregates may help identify new treatment targets. In the future, the researchers hope to expand this technology for broader use in drug discovery, which may provide pharmaceutical companies with more reliable information compared to traditional fluorescent methods, Ibrahim says.

However, he adds, the current tool is limited to studying cells. The researchers aim to expand its use to various sample types, including tissues and organoids, which could boost its relevance in studying diseases.

Reference

Ibrahim, K. A.; Grußmayer, K. S.; Riguet, N.; Feletti, L.; Lashuel, H. A.; Radenovic, A. Label-Free Identification of Protein Aggregates Using Deep Learning. Nat Commun 2023, 14 (1), 7816.

Power up

Mimicking electric eels and cell membranes to generate energy

Cell membranes play a crucial role in regulating the movement of substances in and out of cells. These membranes are made up of a thin layer of fat molecules that block most substances, while proteins act like gates that allow specific molecules to pass through.

Inspired by this efficient design, NCCR Bio-Inspired Materials researchers have created artificial membranes that hold promise for applications such as energy generation and separation methods.

"The big innovation of this work is that we made bio-inspired fluid membranes in such a way that they're stable," says NCCR PI and study co-senior author Michael Mayer, Professor of Biophysics at the Adolphe Merkle Institute in Fribourg. "These membranes mimic biological membranes in many ways," he adds, highlighting their potential for applications in bioengineering and energy conversion.

"The project originated from discussions between myself and NCCR PI Professor Nico Bruns during a winter school, where we brainstormed ideas for an NCCR Bio-Inspired Materials collaborative grant that encouraged interdisciplinary research efforts," he says. Mayer highlights the diverse expertise within the team, which besides Bruns included Dr. Alessandro Ianiro, a physical chemist who led the project from the start, NCCR PIs Professor Ullrich Steiner, who contributed knowledge in self-assembly, and Professor Christoph Weder, who specializes in synthesizing block copolymers – large molecules made up of two or more different types of polymers linked together.

> "The membranes that we developed are a general platform to which we can add selective transporters."
>
> Prof. Alessandro Ianiro

Researchers have recently made progress in creating stable, self-assembled membranes using block copolymers by taking advantage of the boundary between two water-based solutions that do not mix. While this system helps in the assembly process, it isn't enough by itself. To overcome this limitation, the team developed a two-step method that uses an organic solvent to help form and stabilize the block copolymer layers. This approach helped to create large membranes that can be used for practical applications such as separating drugs and generating energy.

One of the project's goals is to mimic the energy-generating mechanisms found in electric eels

With a thickness of about 30 nanometers and a size of about 10 cm^2, these membranes are larger than those produced by other methods, and they can last for several hours before breaking. The membranes act as effective barriers against charged molecules and show self-healing properties after damage, the researchers found.

To increase the functionality of the membranes, the team incorporated a molecule that transports potassium ions into the membrane's hydrophobic core, which enabled it to shuttle the ions across a concentration gradient – much like biological membranes do. This integration not only helps transport ions efficiently, but it also generates a transmembrane potential, which is key for obtaining energy from ion gradients – akin to the way sodium-potassium pumps in neurons allow the cells to fire.

The researchers also aimed to mimic the energy-generating mechanisms found in electric eels by creating membranes that convert ion gradients into electricity. They reported their findings in *Nature*.

Ianiro, who started this project while he was a postdoc with Mayer, notes that it not only addresses energy problems but also has potential applications in desalination and the separation of therapeutic molecules. "The membranes that we developed are a general platform to which we can add selective transporters." However, he adds, "we still need to improve their mechanical stability and integrate more efficient ion channels."

By overcoming the challenges of stability and scalability, Ianiro says, these membranes could revolutionize how we harness natural processes for real-world applications.

Reference

Sproncken, C. C. M.; Liu, P.; Monney, J.; Fall, W. S.; Pierucci, C.; Scholten, P. B. V.; Van Bueren, B.; Penedo, M.; Fantner, G. E.; Wensink, H. H.; Steiner, U.; Weder, C.; Bruns, N.; Mayer, M.; Ianiro, A. Large-Area, Self-Healing Block Copolymer Membranes for Energy Conversion. Nature 2024, 630 (8018), 866–871.

Building blocks

A synthetic polymer that imitates protein folding

In the cell, proteins naturally fold into specific shapes, such as helices, which are essential for their function. Now, NCCR Bio-Inspired Materials researchers have designed a synthetic polymer that can mimic this helical shape by incorporating alternating water-attracting and water-repelling groups along the polymer chain.

These functional groups prompt the polymer to fold into a stable, tube-like structure when exposed to water, much like how proteins fold in cellular environments.

The work provides researchers with a simpler model to study folding mechanics, which is otherwise challenging due to the complexity of real proteins. Recent advancements, such as Nobel Prize-winning work on protein folding, have shown that computers can now predict complex protein structures with remarkable accuracy, says NCCR PI and study co-author Andreas Kilbinger, Professor of Polymer Chemistry at the University of Fribourg. "Yet, our understanding of folding processes hasn't improved much," he says.

To study molecular folding, Kilbinger, and his colleagues combined three distinct approaches: synthetic chemistry, computer simulations, and physical measurements. First, the researchers synthesized water-attracting and water-repelling building blocks using a series of chemical reactions and then polymerized them under controlled conditions.

In water, the hydrophilic sections of the polymer naturally orient toward the solvent, while the hydrophobic segments orient away from it. This self-organization creates a rod-like helical structure with an inner cavity. Using computer simulations, the team had a real-time look at how folding occurred at the molecular level. These simulations revealed that water acts as a "folding trigger," causing the polymers to coil in a stable helical shape. Physical measurements such as nuclear magnetic resonance, small-angle X-ray scattering, and atomic force microscopy confirmed the polymer's helical structure.

> "These synthetic polymers are much more durable and can resist enzymatic breakdown."
>
> Prof. Stefan Salentinig

This collaborative approach was crucial, as each method on its own would have offered only a partial picture of the folding mechanism, says

The shape of the synthetic polymer comes from its alternating building blocks

study co-author and NCCR PI Stefan Salentinig, Professor of Physical Chemistry at the University of Fribourg. The researchers published their findings in the *Journal of the American Chemical Society*.

Beyond the fundamental insights into molecular folding, this research has promising applications. One key area is antimicrobial design. Traditional antibiotics are often broken down by enzymes in the body, which limits their effectiveness. However, Salentinig says, these synthetic polymers are much more durable and can resist enzymatic breakdown, which could make them a promising candidate for developing new antimicrobial treatments.

Another potential application is in water purification and membrane technology. The polymer's tube-like structure could enable selective transport of molecules, which might be used to trap and filter specific contaminants from water or control transport through thin membranes.

Looking ahead, this work could lead to further innovations, such as creating complex molecular structures similar to "molecular Tetris," Kilbinger says, where specific shapes and functionalities are assembled in a controlled manner.

References

Molliet, A.; Doninelli, S.; Hong, L.; Tran, B.; Debas, M.; Salentinig, S.; Kilbinger, A. F. M.; Casalini, T. Solvent Dependent Folding of an Amphiphilic Polyaramid. J. Am. Chem. Soc. 2023, 145 (50), 27830–27837.

118

Researchers

incl. PhD students, postdocs, senior researchers and professors

Gender balance

48% of the NCCR Ph.D. students were women

45% of the postdocs and senior researchers were women

33 Nationalities

including Switzerland, Argentina, Austria, Brazil, Brazil, Bulgaria, Canada, China, Croatia, Egypt, Ethiopia, France, Germany, Greece, India, Ireland, Italy, Japan, Lebanon, Netherlands, Philippines, Poland, Portugal, Romania, Russia, Serbia, South Africa, Spain, Tunisia, Turkey, UK, Ukraine and USA

46

oral presentations at conferences (including 21 keynote and plenary lectures at international conferences)

73

Publications

including 62 original contributions, 9 reviews and 2 book chapters

74%

of open access publications

following the Gold or Green roads and through institutional agreements

Note: All figures between June 1, 2023 – May 31, 2024

In brief

Outreach

The NCCR Bio-Inspired Materials joined the Explora open day at the University of Fribourg in September 2023. The Center's outreach coordinator, Dr. Sofia Martin-Caba, and colleagues focused on the day's theme of taste and colors, more specifically at the nanoscale.

Our Center sponsored the Pint of Science events, organized in Fribourg in May 2024 by NCCR researchers Dr. Liviana Mummolo and Carolina Pierruci along with their AMI colleague Marta Oggioni, which included presentations on biopolymers from NCCR alum Dr. Philip Scholten (Bloom Biorenewables), and on structural color from Center researcher Dr. Viola Vogler-Neuling (AMI).

The Explora open day was well attended

Our NCCR also took part in Fribourg's Museum Night in May 2024. WINS Fellow Dr. Manon Guivier and NCCR staff members Dr. Barbara Drasler and Dr. Lucas Montero presented to attendees the hierarchical structure of wood and how wood-inspired synthetic materials could be created.

Sparkling innovation

Four NCCR researchers were awarded Spark grants by the Swiss National Science Foundation in 2023.

Dr. Anasua Mukhopadhyay (Adolphe Merkle Institute) aims to develop a nanopore-based sensor to detect and quantify mutant protein aggregates that feature in Huntington's disease. This so-far untreatable disorder causes the breakdown of nerve cells in the brain. This research could open the door to improvements in discovering and developing potential therapies.

Dr. Viola Vogler-Neuling (Adolphe Merkle Institute) is investigating how structural color forms in nature in the pupae of butterflies. She is testing the hypothesis that these colors form through the self-assembly of lipidic lyotropic liquid crystals already used in drug delivery. By understanding this process, she hopes to mimic it to develop biocompatible and environmentally friendly photonic pigments for the food and cosmetics industry.

Prof. Jovana Milic (University of Turku) attempts to develop novel metal-free all-organic molecular perovskites using mechanosynthesis strategies. These materials are envisaged to feature exceptional ferroelectric properties, which would, unlike conventional perovskite ferroelectrics, not pose environmental concerns associated with toxic metal components.

Dr. Jules Valentin (Department of Chemistry, University of Fribourg) tackles the issue of biofilm-associated infections. His approach involves the synthesis of drug-delivery systems through self-assembly of monoglycerides and fatty acids. The resulting lipid-based antibiofilm formulations are expected to improve drug pharmacokinetics and efficacy and reduce harmful side effects.

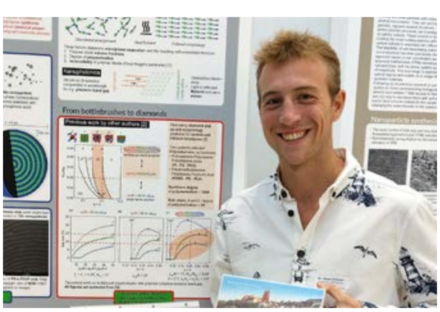
Spark funding is intended for projects with unconventional thinking and a unique approach. The focus is on promising ideas of high originality, relying on no or very little preliminary data that are unlikely to be financed by other available funding schemes. Applicants can request between CHF 50,000 and CHF 100,000 for a project duration of six to twelve months.

NCCR student awards

NCCR PhD students continue to receive recognition at conferences. Meron Debas from PI Stefan Salentinig's group (UniFR) was awarded the Best Poster Award at the 2023 European Colloid and Interface Society Conference, in Naples, Italy.

Meron Debas receiving her award

Another of our PhD students, Thomas Kainz (AMI), was the winner of the 2023 Swiss Nanoconvention's image contest. His colleague, Viola Bauernfeind, was recognized for her student presentation, receiving the Moran Scientific Award at the 2024 Australian Microbeam Analysis Society's symposium in Brisbane, Australia. Finally, Niklas Schwarz (AMI), was the winner of the best poster prize at the 2023 Swiss Soft Days meeting in Basel.



AMI's Niklas Schwarz was also the recipient of a best poster prize at the Swiss Soft Days

Awards

NCCR PI Prof. Francesco Stellacci was appointed in 2024 as a Full Member by the Swiss Academy of Engineering Sciences SATW in recognition of his exceptional contributions to materials science and nanoscience and his groundbreaking approaches to developing broad-spectrum virucides.

The Journal of Nanobiotechnology also recognized Stellacci with its "JNB Trailblazer Award 2023," which honors outstanding achievement

Prof. Francesco Stellacci has been recognized as a trailblazer in his field

and excellence in transformative research and exceptional mentorship by an internationally recognized independent researcher and leader in nanobiotechnology.

New Associate PI

Following his appointment at KU Leuven in Belgium, Prof. Alessandro Ianiro is now an NCCR Associate PI.

Ianiro was already a member of the Center as a postdoctoral researcher at the Adolphe Merkle Institute, where he notably helped launch the ongoing EU-funded Pathfinder project INTEGRATE. This project seeks to develop artificial muscles. His career has taken him so far from his native Italy to Belgium via the Netherlands and Switzerland.

Alessandro Ianiro is pursuing his academic career in Belgium

NCCR alumna Dr. Ivana Domljanovic was selected for the Falling Walls final

Falling Walls

The NCCR Bio-Inspired Materials hosted the first edition of the Falling Walls Lab Fribourg at the Adolphe Merkle Institute as part of a global interdisciplinary pitch competition for students and early-career professionals.

The competition had two winners from the University of Fribourg, Mout de Vrieze, and NCCR alumna Ivana Domljanovic. Both travelled to Berlin in November 2023 to participate in the global final held during the Falling Walls Summit.

New Fellow

NCCR PI Prof. Barbara Rothen-Rutishauser was named a Fellow of the International Society for Aerosols in Medicine (ISAM) in 2023.

This award recognizes recipients' achievements, commitment, and contributions to the society, as well as outstanding contributions in the field of aerosols in medicine. Rothen-Rutishauser received her award at the ISAM conference in Saarbrücken, Germany, along with three other researchers. Rothen-Rutishauser is a past president of the ISAM and has served on multiple international and national advisory committees, including Switzerland's Federal Commission for Air Hygiene.

More than 50 people attended the NCCR-sponsored ISAM Women in Science lunch

As part of the conference, Rothen also organized a Women in Science lunch sponsored by the NCCR to discuss the challenges faced by female scientists, which more than 50 people attended.

The ISAM was founded in 1973 to promote and advance aerosol science internationally, focusing on the health effects of inhaled aerosols, including inhaled drug delivery, to prevent and treat human disease. Its conferences occur every two years and are among the world's largest on respiratory health and inhaled drug delivery.

Prof. Jovana Milic is highly committed to science promotion

International recognition

Prof. Jovana Milic (University of Turku) was appointed in 2023 as one of the International Science Council's 100 new Fellows, the organization's highest honor conferred on an individual.

The council recognizes outstanding contributions to promoting science as a global public good with its fellowships. It is the only international NGO bringing together international scientific unions and associations and national and regional scientific organizations such as academies and research councils from the natural sciences, social sciences, and the humanities. The Swiss Academy of Sciences and the Swiss Academy of Humanities and Social Sciences are members.

Milic also received the 2023 Journal of Materials Chemistry Lectureship, an annual award to recognize outstanding early-career researchers who have made significant contributions to the materials chemistry field.

Buriti fruit oil was featured in a publication highlight from NCCR PI Prof. Stefan Salentinig

Publication highlights

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Emerging investigator

The journal *Materials Horizons* highlighted NCCR PI Prof. Jessica Clough (Adolphe Merkle Institute) as one of its Emerging Investigators of 2023.

The journal delved into some of her most recent work, most notably developing a new methodology for detecting, quantifying, and mapping defects in polymeric materials. Her recent work on non-covalent mechanochromic motifs enables microscopic strain mapping in polymers, advancing imaging techniques to study local properties at high resolution.

Special funding

Two NCCR Independence Grants were awarded to Dr. Matthias Saba and Dr. Viola Vogler-Neuling (Adolphe Merkle Institute).

Saba's goal is to synthesize nanoparticle-based high-refractive index materials. His grant was used to hire support staff for 2.5 months to test the idea before submitting a grant proposal on this topic.

Vogler-Neuling used the funding to create a controlled terrarium environment to breed butterfly pupae in collaboration with the Papillorama. Her goal is to understand the process of structural color formation from purely biological building blocks and thus lay the foundation for bio-inspired color fabrication. A biologist was also hired for 4 months to support the project. The NCCR Bio-Inspired Materials Independence grant aims to help young researchers in their pursuit of an independent academic career. It supports activities that go beyond their work as participants of the Center, such as for example: travel to establish new contacts, preliminary experiments (related to application for their own project / grant), writing of independent publications and own grant writing.

Dr. Viola Vogler-Neuling and Dr. Matthias Saba

Laurens Smulders, winner of the URI best poster prize, with Dr. Barbara Drasler, in charge of the URI program

URI program

The NCCR's summer Undergraduate Research Internship program was once again a success in 2023.

Fifteen students from the Americas and Europe took part, spending up to 12 weeks working on projects. Laurens Smulders of the University of Cambridge, was the winner of the traditional poster prize, rewarding his work on photonics inspired by weevils.

PhD prize

The Swiss Chemistry Society's 2023 DPCI PhD Student Award winner was the NCCR's Matteo Hirsch, who carried out his research in PI Prof. Esther Amstad's laboratory at EPFL.

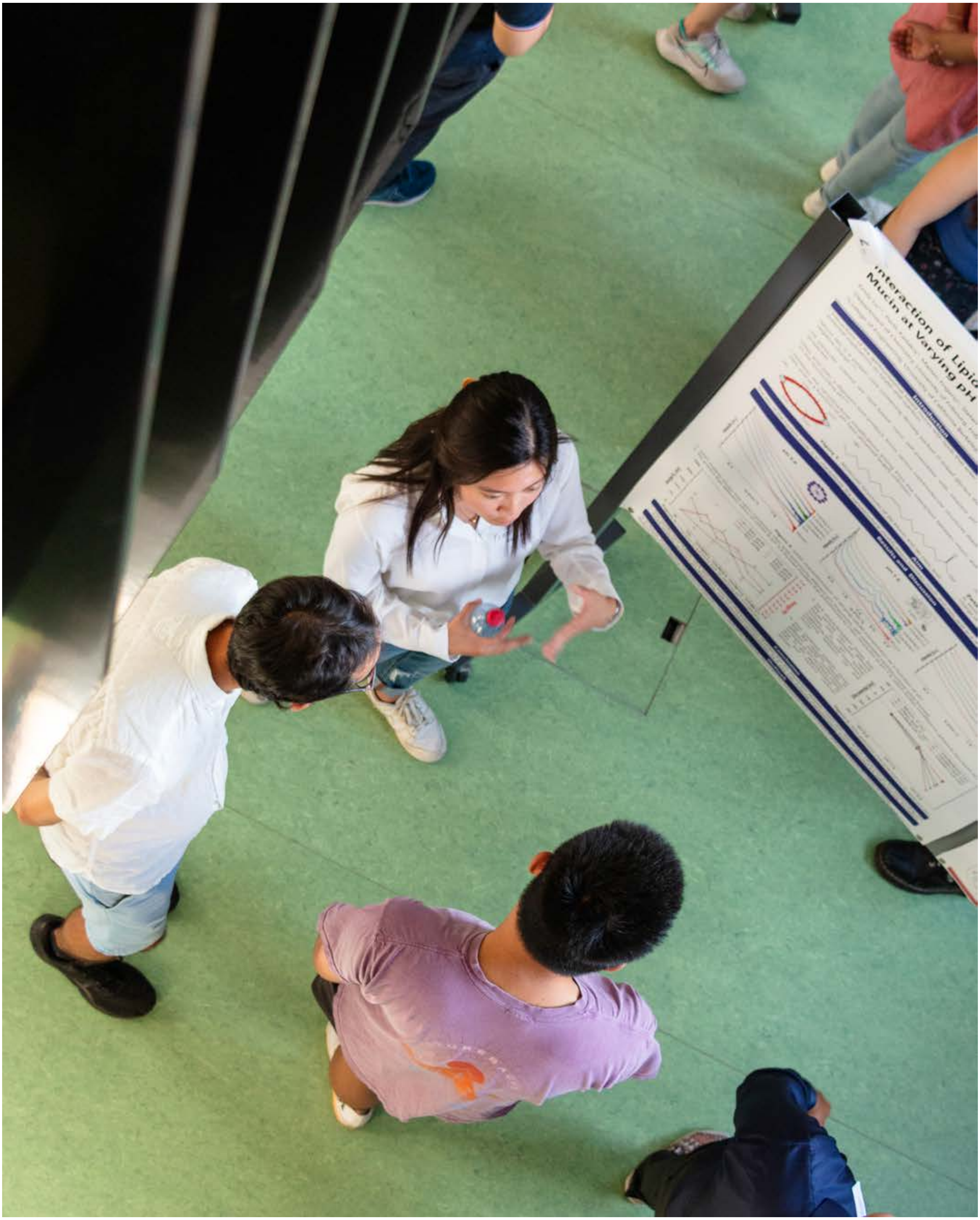
The award recognizes the scientific quality and originality of his research project, "3D printing of living structural biocomposites", focusing on the 3D printing of load-bearing granular hydrogels. These could be used in soft robotics for sensing and, with additional work, also in orthopedics. Other potential uses include art restoration, or regenerating marine reefs as artificial coral.

Close up

Morgane Loretan, an NCCR PhD student at the University of Fribourg in PI Prof. Guillermo Acuna's group, won the 2023 edition of the Fribourg Innovation Challenge with her portable fluorescence microscope equipped with a highly sensitive smartphone camera.

This camera can detect the light emitted by a single molecule, enabling rapid and reliable diagnostics in real time.

The device's portable format allows the device to be used outdoors, particularly in situations where laboratory access is impractical or immediate results are critical. Loretan has already proposed relevant applications, such as detecting bovine diseases or providing diagnostic support in elderly-care facilities.


Interaction of
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Innovation

Developing cancer diagnostics with bio-inspired materials

Xemperia, a medtech spin-off founded in 2023 in the canton Fribourg, is rewriting the narrative of cancer diagnostics with the help of the NCCR Bio-Inspired Materials.

Armed with technologies inspired by nature and developed through years of research, this company aims to transform how we detect and monitor cancer.

Leading Xemperia is NCCR PI Prof. Curzio Rüegg, a cancer researcher whose career has been dedicated to understanding how tumors interact with the immune system. Rüegg's vision for Xemperia was partially born from his work with the Center, an interdisciplinary initiative that blends materials science, physics, chemistry, biology, biophysics, and medicine. The NCCR provided not just the intellectual foundation for Xemperia's technologies but also the collaborative ecosystem needed to bring them to life.

Cancer mutations

Xemperia's current flagship project is a blood test designed to detect breast cancer by analyzing subtle changes in immune cells circulating in the bloodstream. Unlike mammograms, which rely on imaging visible tumors, this test identifies molecular biomarkers that signal the presence of cancer. The company's goal is to propose this test to all women as a first step for breast cancer screening. This approach, however, is particularly valuable for women under 50 or those with dense breast tissue – groups for whom mammography often falls short.

The test works by detecting tumor-induced changes in immune cells. Using standard PCR technology, Xemperia's test delivers results within 48 hours, offering a non-invasive, radiation-free alternative to traditional screening methods. Clinical trials have already demonstrated its potential, showing an impressive 99% sensitivity for early-stage breast cancer.

While the blood test is Xemperia's flagship product, its most futuristic innovation lies in its use of DNA-based nanosensors – tiny structures engineered to detect cancer-related molecules with extraordinary precision. This approach aims to enable non-invasive cancer detection through liquid biopsy, identifying DNA and RNA fragments, including single-nucleotide mutations, with remarkable precision. Developed with NCCR fund-

Detecting breast cancer could be as simple as a blood test

ing, these nanosensors are inspired by nature's ability to self-assemble complex structures from simple building blocks.

The first nanosensor is based on DNA origami technology. Imagine a tiny book made of DNA strands that "opens" when it encounters a specific molecule, such as a cancer-associated microRNA. When this happens, the nanosensor emits a fluorescent signal that can be detected using specialized equipment. These nanosensors are so sensitive they can identify single molecules in a drop of blood – a feat that could revolutionize cancer detection and monitoring. What makes DNA origami so powerful is its programmability. These structures can be designed to detect any microRNA, making them incredibly versatile. To make this technology accessible outside research labs, Xemperia is collaborating with CSEM (Swiss Center for Electronics and Microtechnology) to develop portable fluorescence readers as a point-of-care device. This would allow healthcare providers – even in remote areas – to perform sophisticated diagnostics at a fraction of current costs.

A second technology was developed to detect natural and mutated mRNA faster, more simply, and specifically than traditional techniques like PCR or sequencing. It involves capturing target RNA fragments on microbeads, which isolates the genetic material from other molecules. This is followed by a primer exchange reaction (PER), whereby short pieces of single-strand DNA are specifically bound to the RNA, and branched hybridization, which creates a tree-like structure, to further amplify the fluorescence signal. This signal is then detected by flow cytometry. This process was shown to effectively reveal rare mutations in cancer-related genes (e.g., KRAS, P53, PIK3CA) at low femtomolar concentration, with single-base specificity. The technology is adaptable for detecting multiple mutations in one test, speeding up the diagnostic. By concomitant detection of the standard and mutated gene, it also determines its frequency.

Cross-pollination

Xemperia's journey wouldn't have been possible without the support provided by the NCCR. The Center was established to explore how natural principles – like self-assembly and adaptability – can be applied to create new materials in different fields, including medicine. But, perhaps most importantly, the NCCR fostered collaboration between disciplines. "The NCCR brought together biologists like me with materials scientists and engineers," says Rüegg. "That cross-pollination was key to transforming our ideas into practical tools."

Bringing these technologies from the lab bench to market requires more than just scientific breakthroughs – it demands funding, partnerships, and regulatory expertise. The company secured CHF 100,000 in seed funding from the Foundation for Technological Innovation (FIT), an additional CHF 30,000 from canton Fribour's IFF 2024 Start-Up Award, and CHF 25,000 from the 2025 Ypsomed Innovation Award in recognition of its potential public health impact. Xemperia will collaborate with investors to perform a screening validation study and bring the breast cancer test for CE certification – a critical step toward European commercialization.

> "Cancer doesn't discriminate based on geography or income level – neither should our solutions."
>
> Prof. Curzio Rüegg

While Xemperia's immediate focus is on breast cancer detection in high-income countries, its long-term vision extends far beyond that. Xemperia is exploring ways to make its technologies accessible in low- and middle-income countries, where early detection tools are often unavailable. Portable fluorescence readers and low-cost assays could bring life-saving diagnostics to underserved communities worldwide.

"We want our innovations to reach everyone who needs them," says Rüegg. "Cancer doesn't discriminate based on geography or income level – neither should our solutions."

The GRC Bioinspired Materials takes place in the Swiss resort of Les Diablerets

Bio-inspired conference

Creating a lasting impact on Swiss and international research

Switzerland has boosted its reputation as a global hub for bio-inspired materials research through the partnership between the Gordon Research Conference (GRC) on Bioinspired Materials and the NCCR Bio-Inspired Materials.

Since 2016, this collaboration has brought cutting-edge science to the Swiss Alps, fostering innovations and international collaborations in designing nature-inspired "smart" materials.

The GRC on Bioinspired Materials is a prestigious international scientific event focusing on advancing materials science inspired by nature. Since 2012, it has brought together every two years researchers from diverse disciplines, including biology, chemistry, materials science, engineering, physics, and medicine. The NCCR Bio-Inspired Materials has been a partner since

2016 and was instrumental in bringing the GRC conference to Switzerland.

The event, according to the organizers, aims to present cutting-edge and unpublished research, prioritizing discussion after each talk and fostering informal interactions among scientists of all career stages. The program, spanning five days, includes diverse speakers and discussion leaders from institutions and organizations worldwide, and aims to foster scientific communities with lasting collaborations. In addition to talks, the conference has designated time for poster sessions from individuals of all career stages, and afternoon free time and communal meals allow for informal networking opportunities with leaders in the field.

The Center and GRC share, to a large extent, a common mission: advancing scientific frontiers through collaboration and knowledge exchange. The NCCR focuses on designing “smart” materials inspired by natural systems, with applications ranging from medicine to sustainable technologies. Similarly, GRC’s Bioinspired Materials conference provides an international invitation-only platform for exchanges on fundamental and applied aspects of bio-inspired materials research.

This thematic alignment has made the NCCR a key participant and supporter of GRC events. Researchers from the Center have regularly contributed to GRC conferences – most recently with its former Director, Prof. Christoph Weder, serving as the meeting chair in Les Diablerets Conference Center- showcasing their work on adaptive materials, photonic interfaces, and bio-responsive systems. The 2024 edition featured NCCR Deputy Director Prof. Esther Amstad, and NCCR alum Dr. José Augusto Berrocal as discussion leaders and NCCR PIs Professors Francesco Stellacci, Michael Mayer and Nico Bruns as invited speakers. These interactions spotlight Swiss research excellence and promote cross-disciplinary collaborations with global experts.

The conference also includes a preceding Gordon Research Seminar (GRS), which provides early-career researchers – graduate students and postdoctoral associates – a platform to present their work and network with peers. This mentorship-focused initiative aligns with the NCCR’s commitment to fostering young talent in science.

Switzerland’s hosting of these conferences underscores its strategic importance in global scientific collaboration. The Les Diablerets Conference Center, a frequent venue for GRC events, offers an ideal setting for building lasting scientific networks. The NCCR’s presence at these gatherings has further amplified its role as an international leader in bio-inspired materials research.

The 2026 Gordon Research Conference (GRC) on Bioinspired Materials will be chaired by the NCCR’s Director, Prof. Ullrich Steiner.

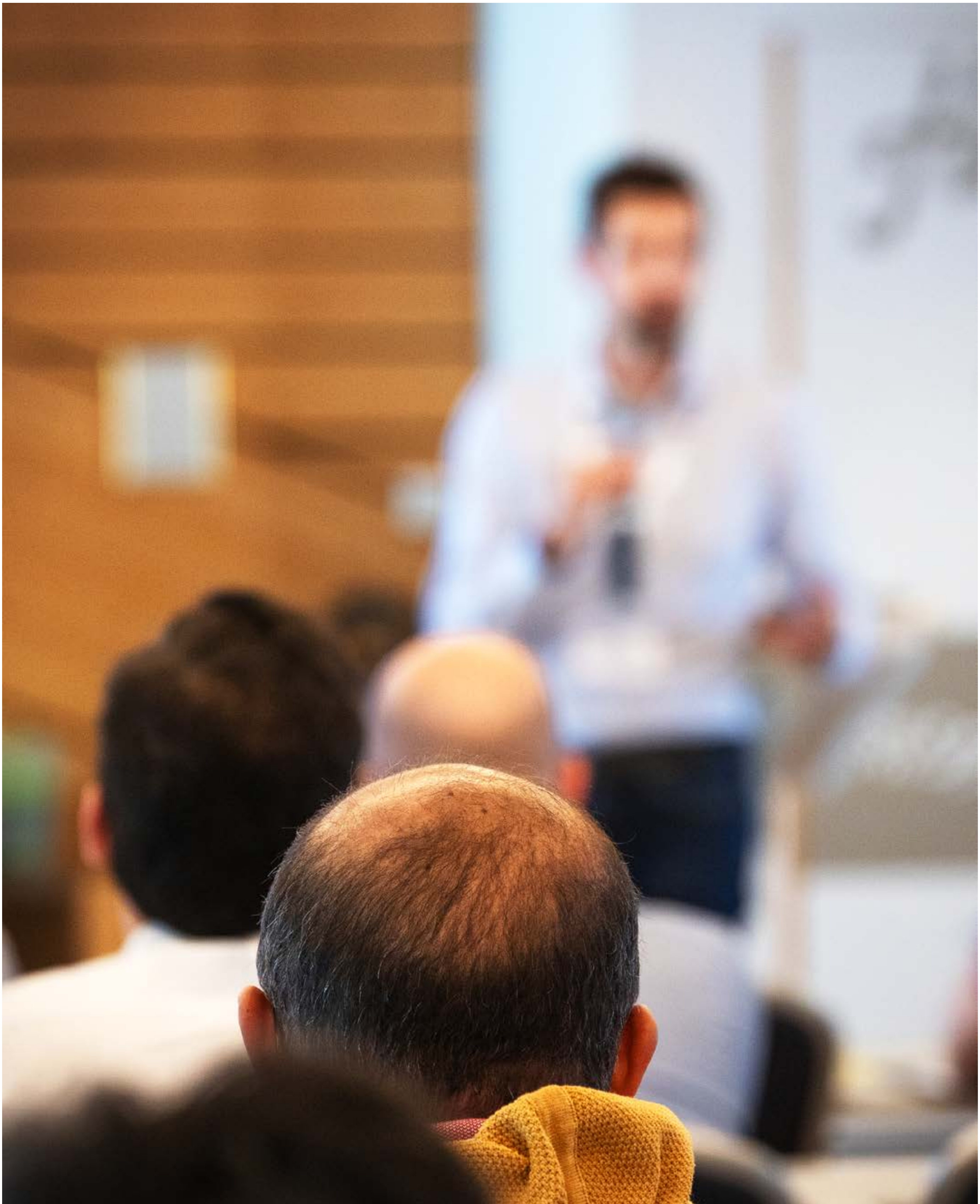
The Gordon Research Conferences

The Gordon Research Conferences (GRC), a nonprofit organization founded in the United States in 1931, continues to be at the forefront of scientific innovation and collaboration. GRC has been bringing together global networks of scientists to discuss cutting-edge, pre-publication research across a wide range of disciplines for over nine decades.

GRC’s unique format sets it apart from traditional scientific conferences. With a focus on discussion and informal networking, these conferences provide a platform for scientists to engage in dynamic exchanges that push the boundaries of their fields. The organization’s commitment to fostering enduring scientific communities has earned it a prestigious reputation in biology, chemistry, physics, engineering, and related technologies.

Today, GRC organizes more than 395 conferences and seminars annually, covering topics from physics to neurobiology and from material science to medicine. These events are known for their intimate setting, with each conference limited to 200 attendees, ensuring active participation and meaningful contributions from all participants.

In addition to the leading conferences, GRC offers Gordon Research Seminars (GRSs) specifically designed for graduate students and postdoctoral researchers. These seminars, together with related GRCs, provide young scientists valuable exposure to the GRC experience.



New horizons

Expanding PhD students' perspectives through diverse experiences

Earning a PhD in science is far more than an academic pursuit confined to the walls of a single laboratory. It is a multifaceted experience that involves developing technical expertise, shaping a scientific profile, and often immersing oneself in new cultural environments.

Recognizing the importance of broadening perspectives, the NCCR Bio-Inspired Materials has developed initiatives designed to enrich doctoral students' experiences and prepare them for future challenges.

One of the programs offered by the Center is the International Graduate Exchange (IGE) program. This initiative allows doctoral candidates to spend several months in laboratories abroad, with grants covering travel expenses, accommodation costs, and student fees. The program aims to expose students to different academic settings, enabling them to gain new insights into their field of expertise while developing valuable skills for their future careers.

Viola Bauernfeind, a PhD student at the Adolphe Merkle Institute's Soft Matter Physics group, spent six months at the University of Queensland in Brisbane, Australia, working with the Marine Sensory Ecology Group. Her research there, extending her work on structural color in nature, focused on the specialized cells known as iridophores that allow cephalopods to change their color and appearance. During her time abroad, Bauernfeind gained fresh perspectives on familiar research topics and learned how to communicate her findings and requirements clearly. She described the experience as invaluable preparation for life as a postdoctoral researcher and emphasized how it helped her adapt to different cultural and organizational environments.

Similarly, Kalpana Manne, a PhD student from the Department of Physics at the University of Fribourg, joined Prof. Stefano Sacanna's group at New York University. "My primary motivation was to expand my research capabilities and explore new scientific domains that align with my interests," explains Manne.

"At NYU, I focused on creating colloidal patchy particles, a topic within the domain of colloidal chemistry. I was fortunate to be hosted by a leading expert whose work bridges chemistry, physics, and materials science. Through this collaboration, I achieved my research goals and gained hands-on experience with self-assembly principles."

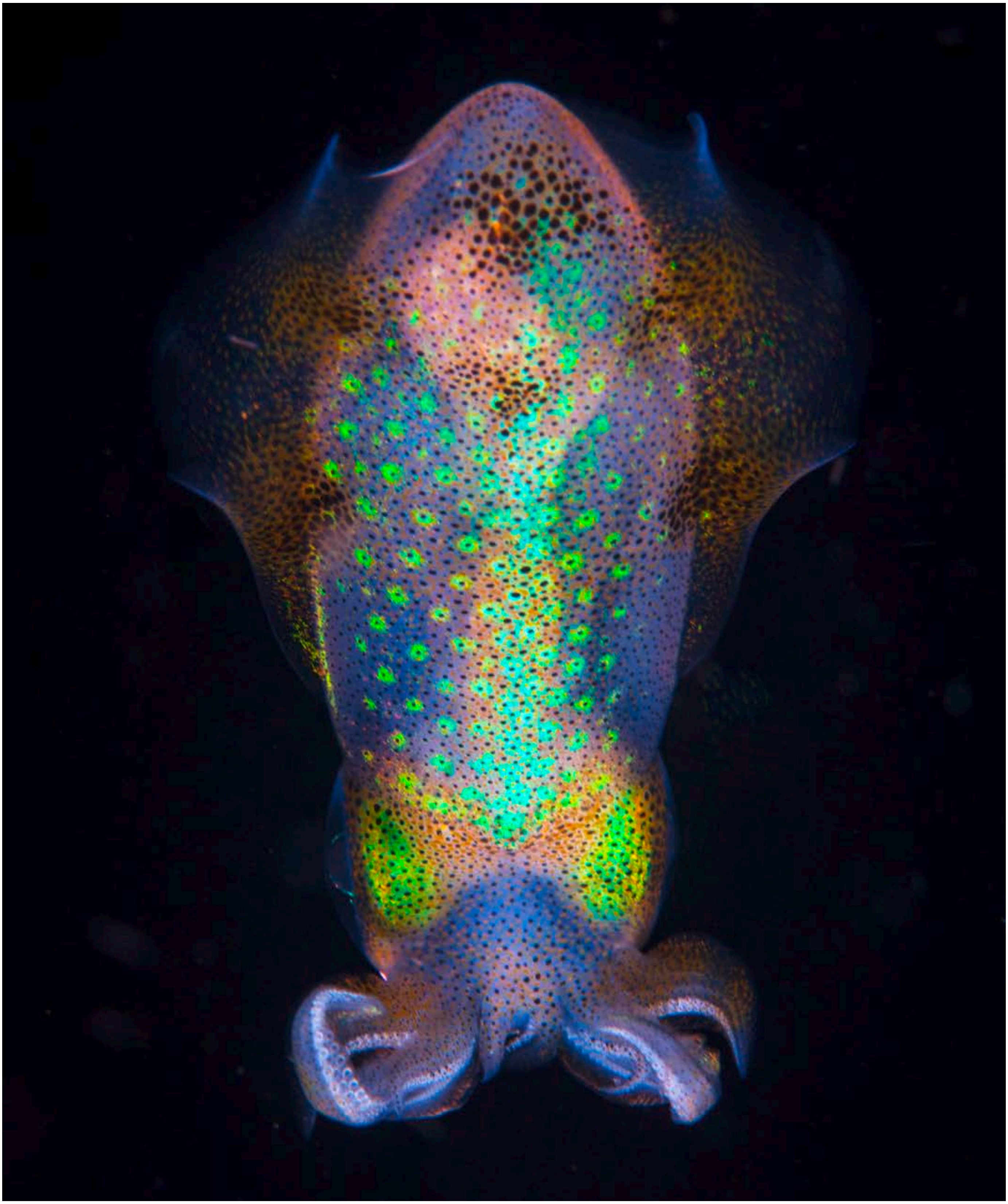
The long-term benefits of these international exchanges are profound. Participants gain technical expertise and exposure to other working meth-

Viola Bauernfeind travelled to Brisbane, Australia, for her exchange

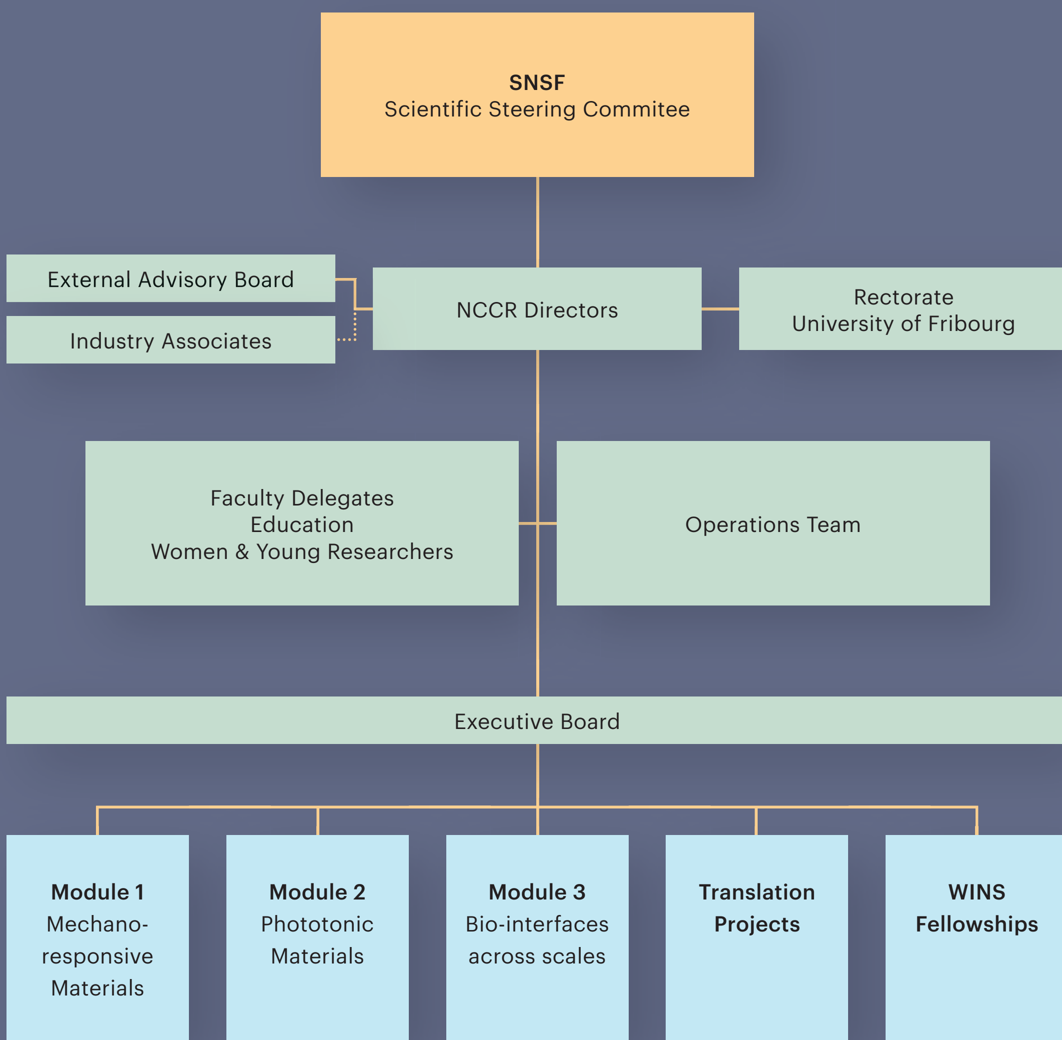
ods and interdisciplinary collaboration. "Diversifying my expertise not only broadens my knowledge but also helps shape a clearer vision for my future career – whether in academia or industry," says Manne. "Gaining exposure to various research areas strengthens my profile and enhances my ability to make informed decisions about my career path."

They expand their professional networks and develop cultural competence that enhances their adaptability in global research environments. These experiences often clarify career paths and open doors to postdoctoral opportunities while fostering innovative research outcomes. "Experiencing a different academic culture was important to me. I think it's crucial to see how research is approached in different systems," points out Bilel Abdennadher, another PhD student from the AMI physics group, who spent time at MIT in Boston. "It broadens your perspective and helps you feel more connected to the global research community."

By covering travel and residency costs for international exchanges, the NCCR demonstrates its commitment to removing financial barriers and supporting the development of its doctoral students. Programs like the IGE are highly recommended for anyone seeking to enrich their PhD journey through diverse experiences. As Bauernfeind stated, "It's an excellent opportunity to widen your horizon before completing your PhD." Through initiatives like this, the NCCR is empowering future leaders in science by equipping them with the tools they need to thrive in an interconnected world.



Organization Phase III



Swiss National Science Foundation

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

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- James Baker (Saint Louis University)
- James Barrett (University of Cambridge)
- Will Galloway (University of Cambridge)
- Isabelle Gray (University of Exeter)
- Adelle Kirschner (California Polytechnic State University San Luis Obispo)
- Sophia Korono (Carnegie Mellon)
- Jonas Kühn (University of Hamburg)
- Emily Lu (University of California Berkeley)
- Jack Moerschel (University of Florida)
- Safaa Mouline (University of California Berkeley)
- Eric Smith (California Polytechnic State University San Luis Obispo)
- Laurens Smulders (University of Cambridge)
- Joaquina Somma (University of Delaware)
- Jose Venegas (Syracuse University)

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Abbreviations:

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

Projects

Module 1: Mechanically responsive materials across different length scales

1. Transiently pulsating materials inspired by the heart
2. Mechanochromic force transducers for biosystems and synthetic hydrogels
3. Atomically thin mechanosensitive membranes for water treatment

Module 2: Biologically inspired assembly of optical materials

4. New opportunities for tuning colloidal crystals using nanorattles
5. Complete photonic band gaps materials by self-assembly of ABC bottlebrush block polymers
6. Enhancing structural colour through absorption
7. Complex disordered photonic architectures by self-assembly
8. Bottom up meets top down: Controlling assembly from mm to nm

Module 3: Responsive bio-interfaces and surfaces

9. Dynamic surfaces for tissue engineering and tissue remodeling
10. 3D printing of functional organoids
11. Increasing dispersion stability with biocompatible small molecules
12. Antiviral Surfaces
13. Design of amphiphilic polymer nanotubes for fighting bacteria
14. DNA Origami-based sensor for the multiplex detection of mRNA in cancer
15. Ion-gradient batteries using ion-selective 2D materials to separate hydrogel compartments with different salt concentration

Translation projects

16. Bright white scatterers beyond titania
17. Healable Polymer Coatings
18. Fabrication of load-bearing, soft actuators
19. Bioinspired 3D printed porous ceramics for solar-to-fuel conversion and carbon capture

WINS Fellowships projects

20. Next generation of polymeric nanovaccine for brain cancer immunotherapy

Publications

Module 1

Boons, R.; Siqueira, G.; Grieder, F.; Kim, S. J.; Giovanoli, D.; Zimmermann, T.; Nyström, G.; Coulter, F. B.; Studart, A. R., 3D bioprinting of diatom-laden living materials for water quality assessment, Small, 2023, 19, 2300771.

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Module 4 (Phase 2)

Belluati, A.; Jimaja, S.; Chadwick, R. J.; Glynn, C.; Chami, M.; Happel, D.; Guo, C.; Kolmar, H.; Bruns, N., Artificial cell synthesis using biocatalytic polymerization-induced self-assembly, Nat. Chem., 2023, 16, 564–574.

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Translation projects

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Other projects

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Adolphe Merkle Institute, University of Fribourg.
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6 round tables

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Note: All figures between June 1, 2023 – May 31, 2024

Seminars

Speaker	Talk	Home Institution	Date
Prof. David Gonzalez Rodriguez	Noncovalent synthesis: From chemically programmed "simple" molecules to complex, self-organized matter	Universidad Autónoma de Madrid, Spain	June 1, 2023
Mr. Fernando Gomollón-Bel	Scicomm in a nutshell: learn how to maximize your impact	Agata Communications, UK	June 2, 2023
Dr. Giulio Ragazzon	What are molecular ratchets and how might we use them?	Institut de Science et d'Ingénierie Supramoléculaires, France	June 12, 2023
Prof. William Shih	Multi-micron crisscross structures grown from DNA-origami slats	Harvard University, USA	September 20, 2023
Dr. Ora Hazak	Dynamic signaling mechanisms in plant root development	University of Fribourg, Switzerland	October 5, 2023
Prof. Steve Eichhorn	Water iteractions with cellulose: Driving the assembly of composites	Bristol Composites Institute, UK	October 23, 2023
Prof. Davis Norris	Optical and electronic Fourier surfaces	ETH Zürich, Switzerland	November 8, 2023
Dr. Helga Rietz	From lab to headlines: The challenges of science communication	ETH Zürich, Switzerland	November 10, 2023
Prof. Pete Vukusic	Biological photonics: a holistic perspective	University of Exeter, UK	November 30, 2023
Prof. Kunal Masania	Additive manufacturing of bio-inspired materials	TU Delft, Netherlands	December 18, 2023
Prof. Stefano Saccana	Crystal Clear: enabling 3D real space analysis of ionic colloidal crystallization	New York University, USA	December 20, 2023
Prof. Ana Akrap	Scientist demystified: Let's unfold the stereotypes together	University of Fribourg, Switzerland	January 11, 2024
Prof. Julia Nentwich	Male Professors' and lecturers' commitment to gender equality at Swiss universities and ETHs	University of St Gallen, Switzerland	February 6, 2024
Prof. Frauke Graeter	Mechano-sensing biomolecular systems	HITS institute, Germany	February 20, 2024
Dr. Fun Man Fung	Building bridges, not beaker walls: Digital learning communities for inclusive chemistry education	National University of Singapore	February 22, 2024
Prof. David Leigh	Giving Chemistry Direction	University of Manchester, UK	February 28, 2024
Prof. Luisa De Cola	Hybrid and supramolecular (nano)materials for biomedical applications	Università degli Studi di Milano Statale, Italy	March 14, 2024
Prof. Emily Pentzer	Polymers, Particles and Printing: Architecting Soft Matter for Energy Management	Texas A&M University, US	March 28, 2024
Prof. Bilal Kaafarani	Ex-ducere transformative education: Creating unique life-changing opportunities for the young minds and empowering tomorrow's leaders	American University of Beirut, Lebanon	April 11, 2024
Prof. Anja Palmans	Folding single polymer chains in functional single-chain polymeric nanoparticles	Eindhoven University of Technology, Netherlands	May 3, 2024
Prof. Tiffany Abitbol	Nature-inspired hybrid biocomposites	EPF Lausanne, Switzerland	May 23, 2024

Impressum

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