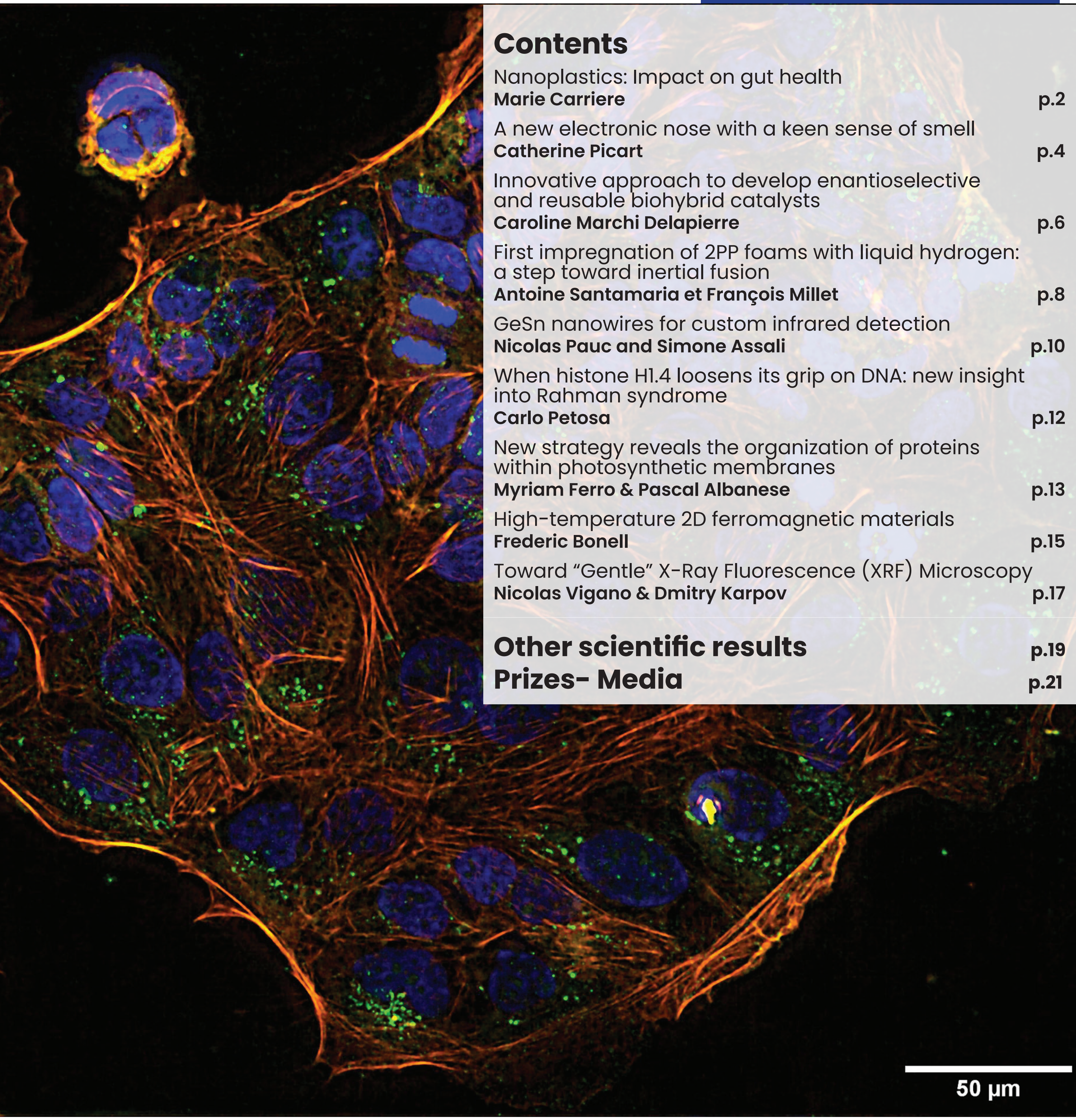
Scientific Newsletter

Fall 2026

Contents



Nanoplastics: Impact on gut health

Marie Carriere
Molecular Systems and nanoMaterials for Energy and Health laboratory

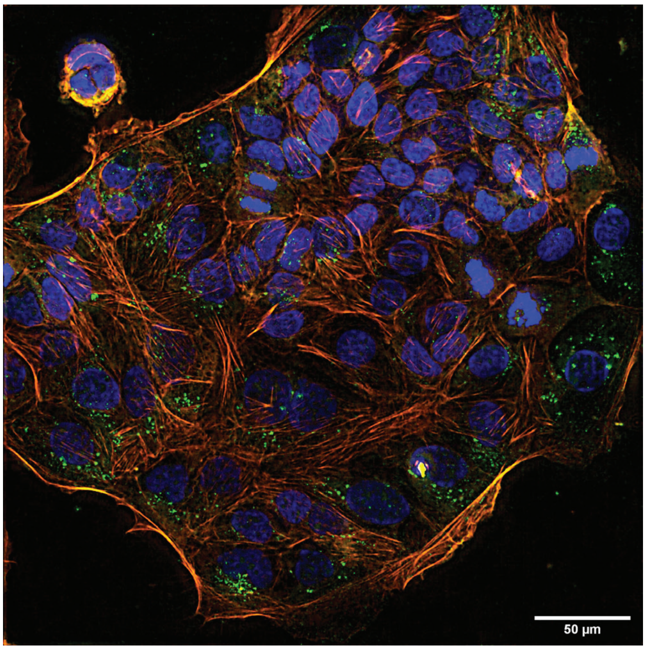
Micro- and nanoplastics (MNP), which result from the degradation of plastic waste, are now present in our water and food. Researchers at CEA-Irig, in collaboration with French and international partners, conducted an in vitro study that reveals that these particles accumulate significantly in intestinal cells, though they do not cause any major toxic effects.

The ubiquity of plastic waste in the environment leads to the formation of micro- and nanoplastics (MNP), which we ingest daily through water and food. Their impact on human health—particularly on the intestinal epithelium and in vulnerable populations, such as people with **Crohn's disease***—remains a major concern. Several studies conducted at CEA-Irig have compared the cellular effects of conventional polymers (**PET, PS**) and biodegradable polymers (**PLA, PCL**)—in their native form or artificially aged under environmental conditions—to assess their potential toxicity in humans.

Using *in vitro* models that replicate the intestinal epithelium of healthy subjects or those with a genetic susceptibility to Crohn's disease, the researchers demonstrated that MNPs accumulated significantly in the cells (up to 20% for PET). Despite this accumulation, only very low **acute toxicity*** was observed in vitro, regardless of whether the polymers were biodegradable or not. The study also reveals that PCL degrades inside the cells and releases oligomers, for which the impact remains limited. Furthermore, weathered particles —simulating their prolonged exposure in the environment— does not increase their toxicity.

In contrast, one of these studies shows that, in vivo, PS MNPs alter intestinal permeability and cause significant toxicity. These results suggest that the effects of MNPs observed in vivo would not originate from a response of the intestinal epithelium, but that other intestinal cell lineages or the **microbiota*** could be involved. It would be worth using a more complex intestinal model so as to more accurately reproduce *in vivo* observations on *in vitro* models.

This research provides new insights into the effects of nanoplastics—whether conventional or biodegradable—on the intestinal barrier. While in vitro models show generally moderate effects, in vivo experiments reveal greater toxicity, suggesting that other cell types are responsible for the in vivo observations. Evaluating these effects using primary intestinal cell culture models or intestinal organoids* could lead to a better understanding of the mechanisms involved. This understanding could then facilitate the development of prevention strategies and, ultimately, appropriate treatment approaches.



Fluorescence microscopy image of intestinal epithelial cells exposed to fluorescent PS MNPs. Orange: cytoskeleton, blue: nucleus, green: PS MNPs.

Crohn's disease*: chronic inflammatory bowel disease that can impair the barrier function of the intestinal epithelium.

Acute toxicity*: adverse effects (impaired viability) observed following short-term exposure to high doses.

Microbiota*: collection of microorganisms (bacteria, yeasts, etc.) living in the gut. It plays an important role, particularly in digestion.

Intestinal organoids*: three-dimensional structures grown in laboratories that replicate certain characteristics and functions of the gut, allowing researchers to study its functioning under conditions that closely mimic those in the body.

PET : polyethylene terephthalate

PS : polystyrene

PLA : polylactic acid

PCL : polycaprolactone

Tutelles UMR : UGA, CEA, CNRS, Grenoble INP

Fundings : ANR (PLASTOX), ANSES (EXMINA), PEPR (Recyclage, recyclabilité et ré-utilisation des matières), Union Européenne (PLASTICHEAL)).

Collaborations : INSERM Institut de recherche en santé digestive (IRSD), Irig-IBS, Irig-LCBM, Iramis-Lions, Université Autonome de Barcelone.

REFERENCE

Bard V, Papin M, Boulée M, Berenguer M, Villacorta A, Fenel D, Dusacq E. Marcos R, Hernandez A, Sergent JA, Douki T and Carriere M.
Toxicity of polyethylene terephthalate and polylactic acid nanoplastics, pristine and weathered in environmentally-relevant conditions, to human intestinal cells representative of genetic susceptibility to Crohn's disease
Food and Chemical Toxicology 2026

A new electronic nose with a keen sense of smell

Catherine Picart
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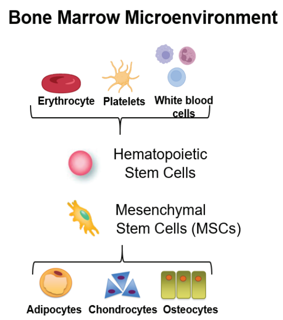

Acute myeloid leukemia (AML) is an aggressive cancer that disrupts the balance of the bone marrow. In this study, researchers at CEA-Irig/BioSanté evaluated the impact of the leukemic microenvironment on mesenchymal stem cells*, which exhibit defects in adhesion and differentiation. These findings pave the way for the development of new therapeutic strategies.

In acute myeloid leukemia (AML), the proliferation of leukemic cells is accompanied by a profound alteration of the bone marrow microenvironment, which promotes disease progression. Among the key players in this microenvironment are **bone morphogenetic proteins*** (BMPs), which regulate cell differentiation and adhesion by interacting with their receptors (**ALK***) and **integrins***. However, their effects on mesenchymal stem cells (MSCs), which are essential for maintaining the bone marrow, remain poorly understood, even though their differentiation capacity is impaired in AML.

In this study, the researchers worked to understand how CSMs adapt to a leukemic microenvironment enriched with BMPs. To replicate this environment, they developed a biomimetic matrix containing various cytokines from the TGF-β superfamily, notably BMPs (BMP-2, BMP-4, BMP-7, BMP-9) and TGF-β1. By comparing CSMs from healthy donors with those from leukemic patients, they analyzed the activation of a signal transduction pathway, cell adhesion and spreading. They also studied the CSMs ability to differentiate into bone, cartilage, and fat cells. They identified three main abnormalities: excessive and persistent activation of the signaling pathway, impaired cell adhesion, and a reduced ability to differentiate. The researchers determined that these abnormalities were due to a dysfunction in the interactions between the ALK5 receptor and integrins.

The ALK5 receptor, which is already involved in several types of cancer, appears to be a promising therapeutic target in AML. ALK5 inhibitors, currently being developed for other cancers, could therefore be evaluated for the treatment of AML disease. Furthermore, the biomimetic material developed and used in this study—which replicates in a simplified manner the microenvironment of human bone marrow—provides a new tool for identifying novel therapeutic targets, evaluating existing treatments, and developing preclinical models that more accurately represent leukemia.

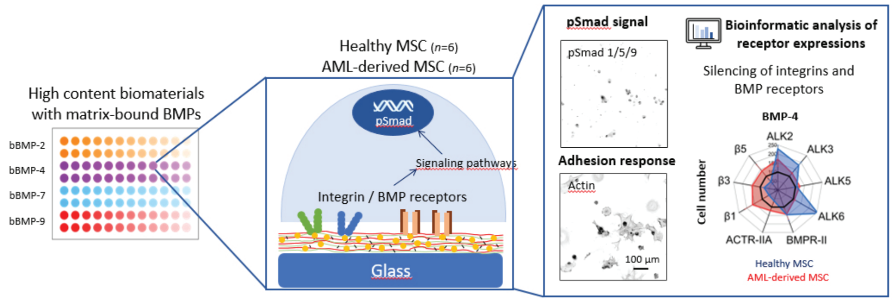

Figure adaptated from I. Arnaldos Perez thesis (2025): A biomimetic material on a 96-well plate that detects alterations in the MSCs of leukemic patients in the pSmad signaling pathway*, cell adhesion, and differentiation, thereby highlighting the specific role of BMP receptors and β-integrins (adhesion receptors).
pSmad signaling pathway*: intracellular signaling pathway activated by proteins of the TGF-β superfamily (including BMPs), which regulates the expression of numerous genes involved in cell development, differentiation, and function. © CEA

Tutelles UMR : Univ. Grenoble Alpes, INSERM, CEA, CNRS.

Fundings : ERC (BioactiveCoatings GA692924), MSD Avenir, INCa, Région AuRA.

Collaborations: Centre de Recherche en Cancérologie de Lyon (CRCL), Institute for Advanced Biosciences (IAB).

Mesenchymal stem cells* (MSCs): adult stem cells found primarily in bone marrow, capable of differentiating into several cell types, including bone, cartilage, and fat cells. They secrete numerous growth factors, cytokines*, and extracellular matrix proteins that promote blood cell renewal, tissue repair, and modulation of the immune response. They thus play an essential role in maintaining the bone marrow microenvironment.

Bone morphogenetic proteins* (BMPs): signaling molecules belonging to the TGF-β (Transforming Growth Factor-β) cytokine* superfamily, which regulate cell development and differentiation, particularly in bone tissue.

cytokines*: signaling proteins that enable cells to communicate with one another and play an essential role in regulating immune responses, inflammation, and cell growth.

ALK* (Activin Receptor-Like Kinases): Type I membrane receptors that transmit signals from cytokines of the TGF-β superfamily (including BMPs), thereby regulating cell proliferation, differentiation, and adhesion. ALK5 is the primary receptor for TGF-β1, but it may also be involved in signaling for certain BMPs (notably BMP-2, BMP-4, BMP-7, and BMP-9).

integrins*: membrane proteins located on the surface of cells that enable them to adhere to their environment (extracellular matrix). They also transmit signals that influence cell behavior (growth, migration, survival, differentiation).

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HArnaldos-Pérez I., Machillot P., Geistlich K., Marchadier L., Maguer Satta V., Migliorini E., Guyon L., Lefort S., Albiges-Rizo C., Picart C.
Biomaterials-enabled revelation of sustained p-Smad signaling and abnormal adhesion of leukemia-derived bone marrow stem cells
Biomaterials 2026

Innovative approach to develop enantioselective and reusable biohybrid catalysts

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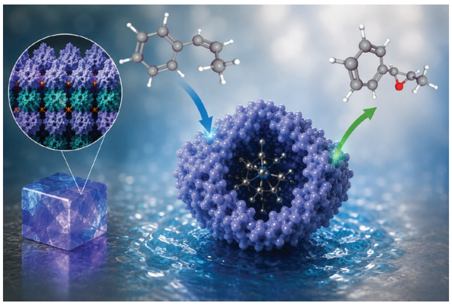

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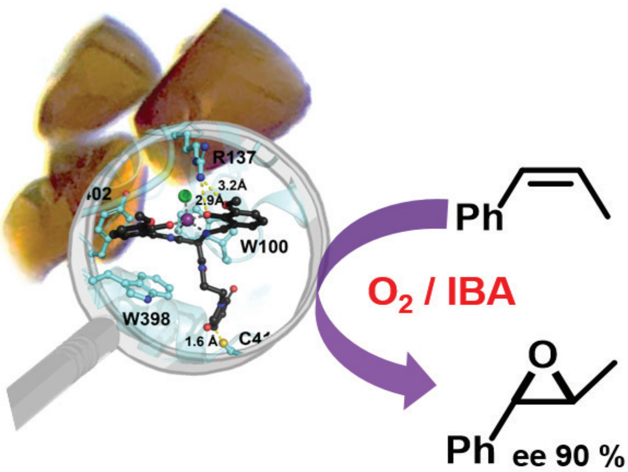
How can artificial enzymes be made both highly efficient and recyclable? Researchers from CEA-Irig/LCBM have demonstrated that protein crystals can serve as a platform for engineering **artificial metalloenzymes*** capable of performing **epoxidation reactions*** with excellent **enantioselectivity***. This approach opens new perspectives for heterogeneous biocatalysis.

Biocatalysis takes advantage of the remarkable properties of enzymes to perform chemical reactions with high efficiency and selectivity. It is a valuable tool for the synthesis of complex molecules, particularly when the selective production of a single enantiomer is required, a major challenge in **fine chemistry*** and pharmaceutical development. To expand the range of accessible chemical transformations, researchers are developing artificial metalloenzymes that combine the selective properties of proteins with the reactivity of inorganic catalysts.

In this study, researchers from CEA-Irig/LCBM have taken a new original step in the design of artificial metalloenzymes by directly constructing an inorganic active site within protein crystals. After stabilization of **cross-linked enzyme crystals*** of **NikA*** (CLEC), a **manganese-based Salen complex*** (Mn(Salen)) was covalently anchored onto an amino acid, a cysteine residue specifically introduced into the protein. This strategy enables the selection of a new organized protein environment for the active site, thereby allowing it to catalyze an enantioselective epoxidation reaction.

Thanks to this newly created artificial active site, the resulting metalloenzyme catalyzes the epoxidation of **cis-β-methylstyrene*** with high enantioselectivity, reaching up to 90% enantiomeric excess. These results demonstrate that CLEC can serve as an effective platform for designing **biohybrid catalysts*** that combine the properties of a protein with those of an inorganic complex. Their use as **heterogeneous catalysts*** also enables the recovery and reuse of these biocatalysts.

This study highlights the potential of cross-linked enzyme crystals as a platform for designing new artificial metalloenzymes. By enabling the direct construction of an artificial active site within a stabilized protein matrix, this approach combines the selectivity of an enzyme with the reactivity of an inorganic catalyst, while providing the advantages of a recoverable and reusable heterogeneous catalyst.



System stabilisation, formation of the catalytic site, and the catalytic reaction – all directly within a crystal. © CEA

Tutelles UMR
CEA - Univ. Grenoble Alpes – CNRS

Fundings
ANR (Labex ARCANE, CBH-EUR-GS, ANR-17-EURE-0003, ANR-21-CE50-0004 and ANR-22-PESP-0010: Project "POWERCO2" within the PEPR project SPLEEN). We acknowledge the European Synchrotron Radiation Facility (ESRF) for provision of synchrotron radiation facilities under proposal number CH-6609

Artificial metalloenzyme*: Hybrid catalyst combining a protein and a metal complex. This approach aims to create new catalytic functions by combining the selectivity of enzymes with the reactivity of metal catalysts.

Epoxidation*: Addition of an oxygen atom to a double bond between two carbon atoms in unsaturated hydrocarbons, forming a three-atom ring called an epoxide.

Enantioselectivity*: The ability of a catalyst to preferentially promote the formation of one of the two three-dimensional forms (enantiomers) of the same molecule. This selectivity is essential when the two enantiomers have different biological properties.

Fine chemistry*: Field of chemistry that designs and manufactures complex, pure, high-value-added molecules, typically produced in small or medium quantities. These molecules are intended for various sectors, including pharmaceuticals, agrochemicals, cosmetics, electronics, and perfumery. The focus is on mastering synthesis processes, quality, purity, and reproducibility. Pharmaceutical chemistry is one example.

Cross-Linked Enzyme Crystals (CLEC)*: Enzyme crystals stabilized by chemical bonds between protein molecules. This approach preserves the protein's structure while improving its stability and facilitating its use as a recoverable and reusable catalyst.

NikA*: A protein found in the bacterium Escherichia coli capable of transporting nickel ions (Ni^{2+}) across the membrane.

Salen-type manganese complex*: Inorganic complex containing a manganese ion held at the center of a molecular clamp by a Salen-type ligand.

Cis-β-methylstyrene*: Aromatic alkene derived from styrene, used as a model to evaluate the catalyst's efficiency and selectivity.

Biohybrid catalyst*: A catalyst that combines biologically derived components, such as proteins or enzymes, with synthetic components, such as metal complexes, to create new catalytic properties.

Heterogeneous catalysis*: Catalytic process in which the catalyst is in a different phase from the reactants—for example, in solid form in a liquid reaction medium. This approach facilitates the recovery and reuse of the catalyst.

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Boukhallat M, Benhamed I, Arnone J, Van Baaren S, Rinaldi C, Catty P, Marchi-Delapierre C, Cavazza C, and Ménage S.
Covalent Insertion of a Mn(Salen) Type Complex in Cross-Linked Protein Crystals: Design of an Enantioselective Artificial Epoxidase.
Chemistry 2026

First impregnation of 2PP foams with liquid hydrogen: a step toward inertial fusion

Antoine Santamaria et François Millet
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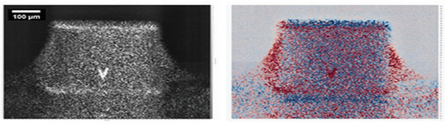


Laser speckle image of the 2PP foam sample impregnated with LH2 (L) and detection of LH2 presence using the LSCI technique (R)*

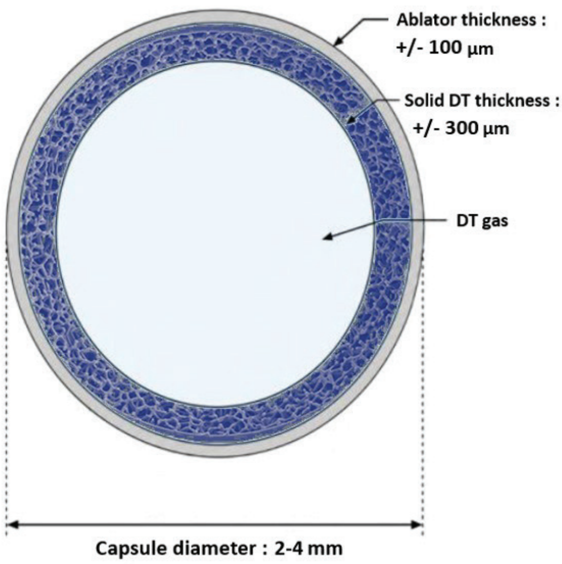
Inertial confinement fusion (ICF)* requires ultra-homogeneous cryogenic deuterium-tritium (DT) targets in order to optimize the **thermonuclear gain***. The CHIMERA cell (CEA-Irig/DSBT), designed to replicate controlled cryogenic conditions, enabled the first successful impregnation of liquid hydrogen (LH_2) into **micrometer-scale 2PP foams***.

In inertial confinement fusion (ICF), the cryogenic deuterium-tritium (DT) target is a key component of the system. Its design—whether in solid/gas or liquid/gas configurations—must encompass strict requirements for uniformity and reproducibility, as it directly impacts the thermonuclear gain and, consequently, the reactor's overall energy efficiency. Near-perfect homogeneity is essential to ensure optimal fusion reactions, as is the case for the TARANIS reactor, a project led by the French startup GenF. It is in this context that porous structures fabricated by two-photon polymerization (2PP) are proving particularly promising. Thanks to their high dimensional precision, these micrometer-scale foams allow for impregnation with liquid hydrogen (LH_2). Once this step is mastered, it is possible to solidify the LH_2, thereby achieving optimal homogeneity in solid hydrogen.

To study and control the impregnation processes of cryogenic targets, a dedicated experimental cell, named CHIMERA, was designed. Its primary function is to reproduce controlled cryogenic conditions (temperature and pressure) and to induce condensation directly in contact with the sample, thereby enabling impregnation via capillary action into the porous structure. Using this setup, an initial impregnation with liquid hydrogen (LH_2), followed by solidification, was successfully carried out. This initial process, whose parameters (rate, front, uniformity) have yet to be quantified, paves the way for a deeper understanding of the mechanisms involved.

The results obtained with the CHIMERA cell mark a first decisive step toward mastering the impregnation and solidification processes of cryogenic targets using 2PP foams. The next test campaign will aim to precisely quantify the impregnation dynamics, specifically by studying the influence of the structure and density of 2PP foams on this phenomenon. These data will enable us to refine the models and optimize the parameters to ensure homogeneity and reproducibility in line with the requirements of FCI reactors.

In the longer term, the goal is to design a solution suitable for a high rate (10 Hz), which is essential for feeding the TARANIS reactor under real-world conditions. The ultimate objective is to translate these results into a system capable of producing high-performance cryogenic targets at a high rate, while maintaining the design criteria necessary to maximize the thermonuclear gain.



Schematic of a cryogenic target design for inertial fusion: an outer capsule acts as an ablator during compression, a 2PP foam (in blue) is impregnated with liquid or solid deuterium-tritium (DT) fuel, which is in equilibrium with its gaseous phase at the centerntre. © CEA.

Tutelles UMR (E 9004)
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Collaborations
CEA-IRAMIS/SPEC
CEA-IRESNE/STMA

Fundings
Programme Transversal de Compétences « Instrumentation et Détection

inertial confinement fusion (ICF)*: fusion of hydrogen nuclei through the extremely rapid compression of a tiny fuel capsule (composed of a mixture of hydrogen isotopes—deuterium and tritium)—using very powerful lasers. To achieve maximum efficiency, the fuel is solidified at a very low temperature inside the capsule. The goal is to produce abundant, carbon-free, and sustainable energy.

thermonuclear gain*: the amount of energy produced by fusion reactions relative to the energy required to initiate them.

micrometric 2PP foams*: three-dimensional porous structures with a controlled architecture at the micrometer scale, manufactured by two-photon polymerization (2PP, a 3D printing technique using an ultrafast laser). These foams are designed to serve as cryogenic supports, enabling uniform impregnation of the liquid fuel.

laser speckle contrast imaging (LSCI)*: A laser speckle is a grainy pattern scattered by a surface illuminated by coherent laser light. By analyzing contrast variations and temporal changes, it is possible to detect physical phenomena such as the presence of a liquid.

GeSn nanowires for custom infrared detection

Nicolas Pauc and Simone Assali
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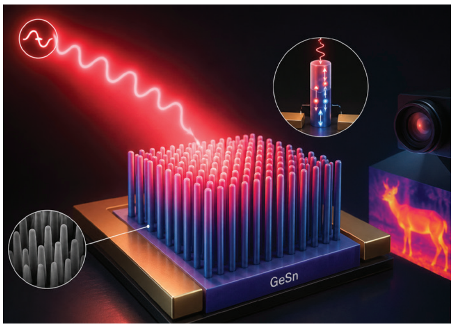

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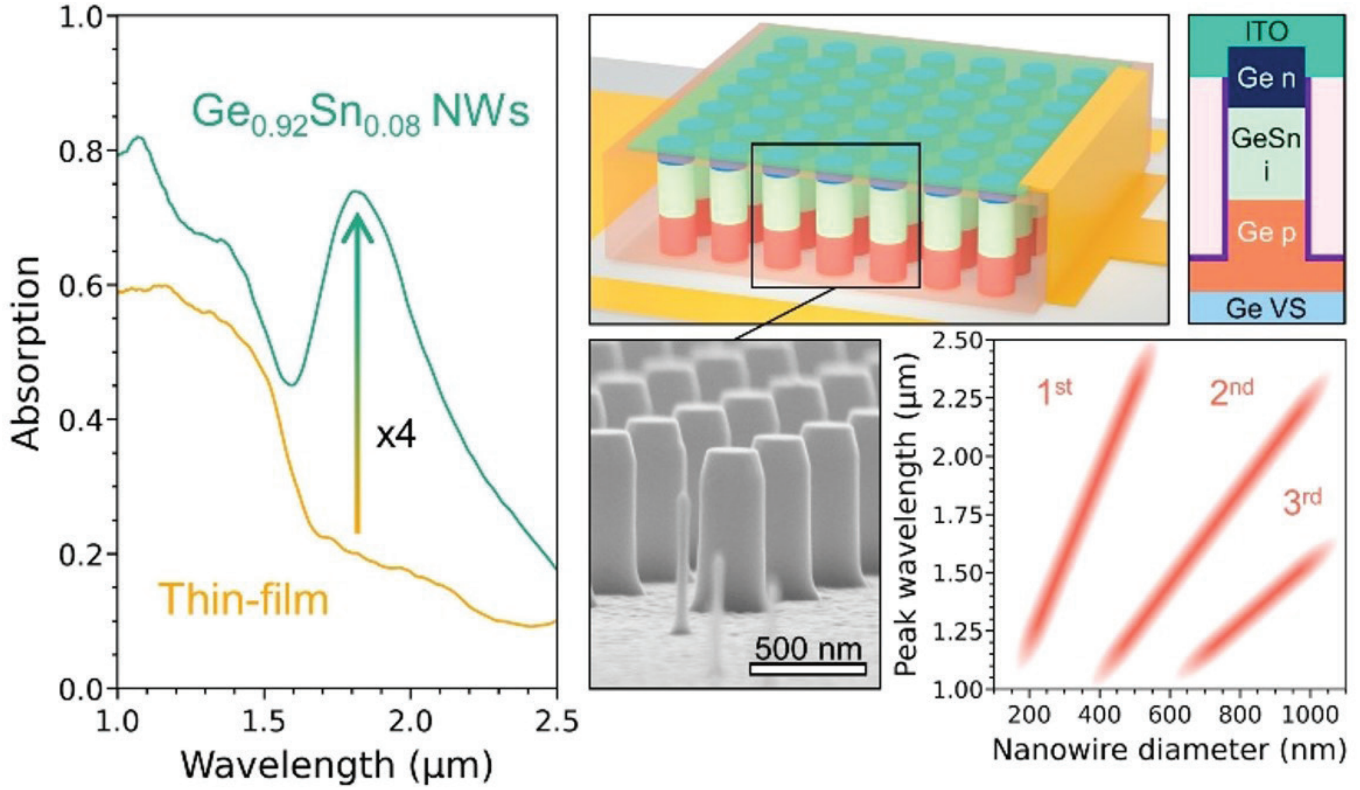
The development of detection and data transmission technologies in the infrared range using Germanium Tin (GeSn) semiconductors is expanding fast. In this context, researchers from CEA-Irig/PHELIQS, in collaboration with CEA-Leti, have developed a room-temperature photodetector based on a GeSn nanowire array. This innovative architecture enhances absorption and expands the device's functionality in the short-wave infrared (SWIR) range.

Detection in the Short-Wave Infrared (SWIR: 1.5–3.0 µm) is critical to many applications, such as imaging under low-visibility conditions (e.g., fog), gas detection, and biomedical diagnostics. Currently, the most sensitive SWIR detectors rely on **direct bandgap* III-V and II-VI semiconductors***. In addition to their complex and costly fabrication—often requiring cryogenic cooling—these devices are grown via **epitaxy*** on specific substrates, which complicates their integration with CMOS silicon technologies*. These limitations are driving the development of alternative materials, such as the recently stabilized group IV semiconductor alloys of the germanium-tin ($Ge_{1-x}Sn_x$) family, which can be epitaxially grown onto silicon wafers. These materials exhibit a direct bandgap at wavelengths longer than 2 µm and tin contents x greater than 8%, which enables high optical absorption.

The researchers nanostructured thin films of Ge0.92Sn0.08 by etching them into ordered arrays of vertical nanowires, each with diameters of a few hundred nanometers and heights of one micrometer. This architecture enhances the electromagnetic field within the semiconductor structures by trapping light through **leaky-mode resonances (LMRs)***. As a result, light absorption is quadrupled compared to a conventional thin film. By adjusting the nanowire diameter from 200 to 1 000 nm, the resonance peaks can be precisely tuned for wavelengths between 1 and 2.4 µm. Each nanowire then functions like an infrared-optimized nano solar cell: at a resonant wavelength determined by its dimensions, the nanowire network efficiently converts the incident flux of light energy into an electrical current that can be directly read by a measurement instrument. The device operates without an external voltage and thus at a reduced power consumption.

Working at room temperature and with a precise control of its spectral absorption, this device paves the way for a new generation of compact infrared sensors that can be directly integrated into **eye-safe LiDAR systems*** and infrared spectrometers. Ongoing work aims at improving their sensitivity by optimizing the fabrication process, particularly through better surface treatment to reduce electronic defects that cause signal loss. Additionally, efforts are focused on extending their operation into the mid-wave infrared (MWIR: 3–8 µm) by increasing the tin concentration in the GeSn alloy. At longer term, improvements in GeSn epitaxy processes will enable higher tin content, reaching the long-wave infrared (LWIR: 8–20 µm) and thus enabling the development of multispectral imaging systems across the entire infrared range.



Schematic of a GeSn nanowire array photodetector exhibiting enhanced infrared absorption and an LMR peak that is tunable with the nanowire diameter. © CEA

Tutelles UMR
CEA – UGA – Grenoble INP-UGA

Fundings: ANR (SINPHONI), CEA PTC (SAGE), UGA (SAGE)..

Collaborations: CEA-Leti

REFERENCE
Willoquet T, Pauc N, Turmel M, Hartmann J-M, Calvo V and Assali S.
Tunable SWIR absorption peaks in GeSn nanowire array photodetectors
ACS Photonics 2026

II-V and II-VI semiconductors*: crystalline materials composed of elements from the III and V, or II and VI columns of the periodic table, such as GaAs or HgCdTe, widely used in optoelectronics. Their electronic structure generally features a direct bandgap*, which depends on their composition. This enables targeting of different operating wavelengths.

Bandgap*: In a semiconductor crystal, energy range where no electronic states are allowed. It is bounded by the extrema of the valence and conduction bands. The emergence of a bandgap enables the control of populations of free electrons or free holes and allows for optical transitions, forming the foundation of modern electronics and optoelectronics.

Epitaxy*: it is the science of crystal growth on a substrate. During this process, deposited atoms arrange according to the lattice structure of the underlying crystal, enabling the production of high-quality materials. III-V semiconductors must be deposited on specific III-V substrates (e.g., GaAs, InP), which increases fabrication costs and limits their integration with CMOS technologies on silicon*.

CMOS technology on silicon*: CMOS stands for Complementary Metal-Oxide-Semiconductor, an industrial process used to manufacture electronic circuits on silicon wafers. This technology enables large-scale, reliable, and cost-effective production.

Leaky-mode resonances (LMRs)*: Depending on the wavelength and the nanowire's dimensions, particular light path channels resulting in temporarily trapped light that propagates through the nanowire before escaping.

LiDAR systems*: LiDAR stands for Light Detection And Ranging. These remote sensing systems determine the distance between a sensor and an object by measuring the travel time of a laser pulse reflected by the object.

When histone H1.4 loosens its grip on DNA: new insight into Rahman syndrome

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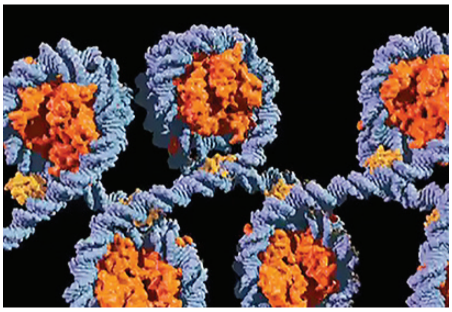

Researchers at CEA-Irig/IBS, as part of an international consortium, have shown that a mutation in histone H1.4 reduces the compaction of **chromatin*** and makes DNA more accessible, providing new molecular insight into a rare genetic disordera.

Rahman syndrome is a rare genetic disorder marked by neurodevelopmental defects and distinctive facial features, often accompanied by skeletal or cardiac abnormalities. It is caused by mutations in histone H1.4, a protein that helps package DNA inside the cell nucleus. How these mutations alter DNA organization and lead to disease remains poorly understood.

DNA is wrapped around core **histones*** to form nucleosomes, the basic units of chromatin. Histone H1.4 is a linker histone that binds where DNA enters and exits the nucleosome and brings these DNA segments together, helping to compact chromatin. Rahman syndrome mutations alter a DNA-interacting region of H1.4, weakening its ability to hold these DNA segments together. As a result, chromatin becomes more open and flexible, making the DNA more accessible. This effect can be seen in how chromatin condenses: under the microscope, the mutant protein changes the formation and appearance of condensates produced by phase separation. Because chromatin compaction helps control which genes can be read by the cell, these changes could disturb gene regulation during development and help explain the disease.

These findings reveal how histone H1.4 helps organize chromatin and provide new molecular insight into Rahman syndrome. More broadly, they open new avenues for studying how defects in chromatin organization alter gene regulation and contribute to disease.

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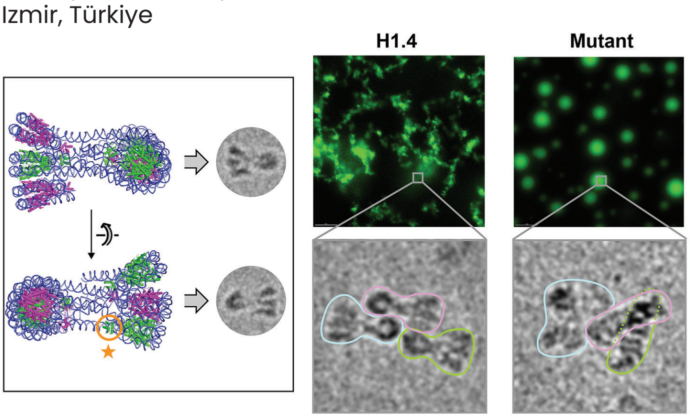
Fundings: ANR RAHMAN, GRAL/CBH-EUR-GS (ANR-17-EURE-0003).

Chromatin* : the form in which DNA is packaged and organized inside the cell nucleus. Its structure helps determine which genes are accessible and can be expressed.

Histones* : proteins that DNA wraps around. They help to compact and organize DNA inside the cell nucleus.

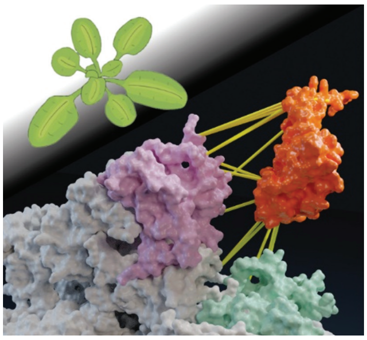


The H1.4 mutation disrupts chromatin compaction and phase separation. The inset on the left shows a compact chain of six nucleosomes bound to H1.4, viewed from two orientations, as well as the corresponding simulated cryo-EM images. The orange star marks the position of one of the H1.4 molecules. On the right, the upper panels show fluorescence microscopy images of the condensates formed by phase separation, while the lower cryo-EM panels show how nucleosome chains are organized. With normal H1.4, the chains adopt compact, relatively regular structures and form fibrous condensates. With the mutant protein, they remain more open and irregular, giving rise instead to rounded, droplet-like condensates© CEA

REFERENCE
Boopathi R. et al.
A Rahman Syndrome mutation in histone H1.4 disrupts chromatin compaction and phase separation.
Nature Communications 2026

New strategy reveals the organization of proteins within photosynthetic membranes

Myriam Ferro & Pascal Albanese
Biology and Biotechnology for Health Laboratory
Cell & Plant Physiology Laboratory

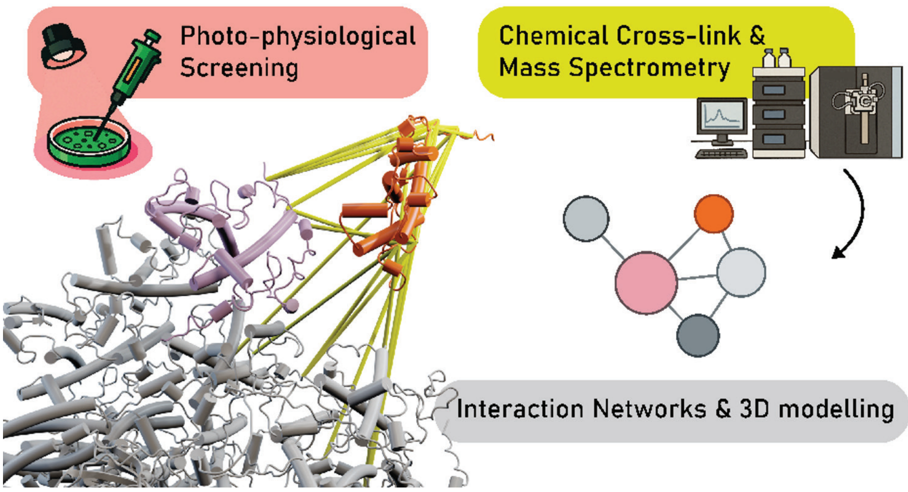


How do thylakoid membrane proteins organize themselves and work together to enable efficient photosynthesis? Researchers at CEA-Irig, from the BGE and LPCV laboratories, have successfully mapped these interactions in their native state. This breakthrough opens up new avenues for the integrative study of functional membrane systems, far beyond photosynthesis.

Photosynthesis is a process essential to life on Earth: it enables photosynthetic organisms (plants, algae) to convert light energy into chemical energy that can be used by the cell. Its efficiency depends in particular on the three-dimensional organization of numerous proteins present in the **thylakoid membranes***. To understand how these proteins assemble and function together, researchers are developing **proteomics approaches*** to identify proteins that interact with one another. Among these approaches, **cross-linking*** coupled with **mass spectrometry (XL-MS)*** makes it possible to detect protein-protein interactions and reconstruct their networks. In this study, researchers at CEA-Irig developed an innovative strategy to map the protein networks of functional photosynthetic membranes.

The researchers optimized the method based on cross-linking coupled with mass spectrometry (XL-MS) by combining the cross-linking agent, **PhoX***, with a chemical agent, **TMPAC*** (trimethylphenylammonium chloride), to obtain reliable results while preserving the functional integrity of the membranes. This strategy enabled the identification of several hundred interactions—increasing their detection rate by 20 to 40 percent—between proteins involved in the regulation of photosynthesis. By combining these data with artificial intelligence (AI) modeling, the researchers revealed previously unknown associations involved in the tuning and repair of the photosynthetic machinery, thereby providing a precise understanding of the organization of the molecular complexes responsible for the conversion of light energy.

This research demonstrates that the method developed bridges the gap between functional and structural biology in plants by enabling the systematic exploration of protein networks under conditions close to physiological conditions. This approach provides a methodological framework that can be applied to other membrane systems—which are often difficult to study—paving the way for the modeling of new functional protein complexes.



Improved chemical cross-linking approach to decipher protein networks in thylakoids membrane. © CEA

Tutelles UMR: Irig/PCV-LPM (UGA-CNRS-CEA-INRAe) ; Irig/BGE-EDyP (UGA-CEA-Inserm).

Fundings : ANR (PHOTO_DYN), Union Européenne (PhotoLINK, Chloro-Mito, PlanktON), ProFI.

Collaboration : UGA, CNRS, CEA, INRAe, Inserm.

Thylakoid membranes*: membrane structures located inside chloroplasts, organelles in plant cells (and algae) responsible for photosynthesis. The initial stages of photosynthesis (capturing light and converting it into chemical energy) take place at these membranes.

Proteomic approaches*: analytical techniques used to identify and quantify proteins in cells, biological fluids or any other sample containing proteins.

Cross-linking* (XL): a technique based on the use of a chemical reagent capable of creating a covalent bond between two proteins that are sufficiently close to each other. This approach allows their interactions to be frozen so that they can be investigated for a better understanding gained of how these proteins organize and function together.

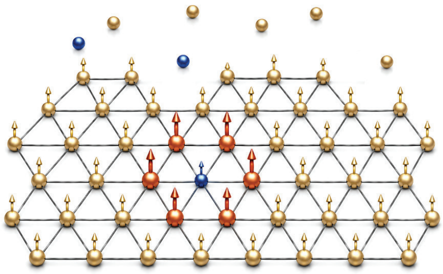
Mass spectrometry (MS)*: an analytical technique used to identify and quantify proteins. When combined with cross-linking (XL-MS stands for Cross-Linking Mass Spectrometry), it enables the detection of chemically linked proteins and the reconstruction of the protein network's organization within a biological system.

PhoX*: a negatively charged cross-linking reagent, which may limit its access to membrane surfaces that are also negatively charged, such as those of thylakoids. The addition of **TMPAC***, a positively charged compound, reduces these electrostatic repulsions and improves PhoX's accessibility to membrane proteins, while preserving the structural integrity and biological activity of the membranes.

REFERENCE
Frances N, Giustini C, Finazzi G, Ferro M. et Albanese P.
Deciphering photosynthetic protein networks: a crosslinking-MS strategy for studying functional thylakoid membranes
The Plant Journal 2026

High-temperature 2D ferromagnetic materials

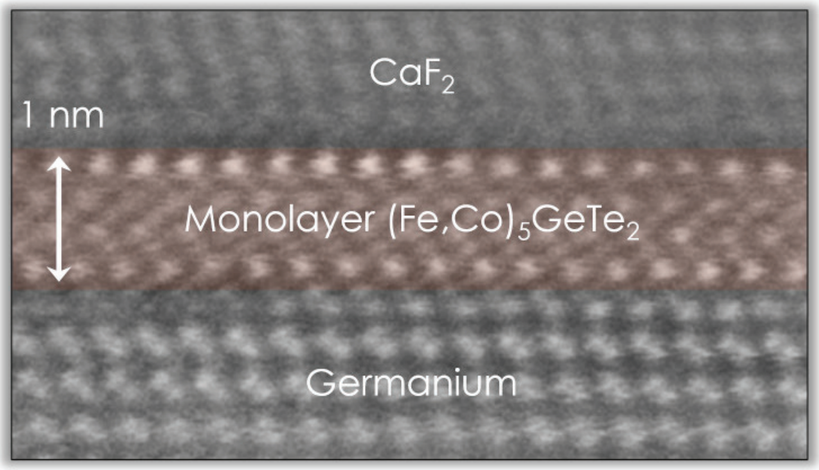
Frederic Bonell
Spintronics and Technology of Components laboratory

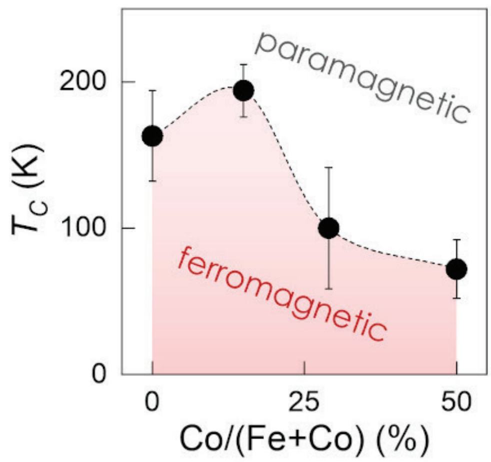


Thanks to their extremely low thickness, van der Waals-type two-dimensional (2D) materials* show great advantages for spintronics* and the design of new electronic components. However, their magnetic properties are limited to temperatures well below room temperature. Researchers at CEA-Irig/SPINTEC have recently developed ultrathin layers that exhibit ferromagnetic properties* at significantly higher temperatures.

The two-dimensional nature of van der Waals (vdW) magnetic materials could enable the creation of ultracompact devices with sharp interfaces at the atomic scale, paving the way for enhanced and tunable spintronic functionalities. To date, these materials have been studied primarily as micrometer-scale fragments derived from bulk crystals, with limited control over their thickness and lateral dimensions. The development of methods to fabricate atomically thin layers over large areas has therefore become essential. Furthermore, vdW magnetic materials lose their spontaneous magnetization and thus, their ferromagnetic properties, at temperatures well below room temperature when in their thinnest form.

Researchers at CEA-Irig/SPINTEC have succeeded in synthesizing, *via* **molecular beam epitaxy***, thin films of Fe_5GeTe_2 doped with cobalt (Co), on centimeter-square areas. These films exhibit stable ferromagnetism well above room temperature (293–298 K), up to approximately 370 K. Using a germanium (Ge) substrate, the researchers then gradually reduced the thickness of the material until they obtained a single atomic layer. At an optimal Co concentration, this monolayer remains ferromagnetic up to approximately 200 K, a remarkable temperature and, to date, unprecedented for a van der Waals (vdW)-type 2D material. By combining synchrotron experiments —a technique called **X-ray circular magnetic dichroism (XMCD)*** — with *ab initio* calculations, the researchers were able to distinguish the magnetic contributions of iron (Fe) and cobalt (Co). They thus demonstrated that, although Co atoms are weakly magnetic, their presence enhances the magnetism of neighboring Fe atoms thanks to locally boosting the magnetic exchange interaction. The simulations also confirmed that Co atoms directly substitute for certain Fe atoms in the crystal structure. This mechanism explains why Co doping enhances the ferromagnetism of Fe_5GeTe_2 regardless of the material's thickness, down to the limit of a single atomic layer.





Left: A cobalt-doped Fe5GeTe2 monolayer, resolved at the atomic scale (transmission electron microscopy). Right: Magnetic transition temperature as a function of doping level. A maximum is observed when one out of every five iron atoms is replaced by a cobalt atom. © CEA

These results provide a better understanding of the mechanisms underlying magnetism in 2D van der Waals materials. They also open up new possibilities for their integration into next-generation spintronic devices, particularly thanks to the ability to fabricate ultrathin layers via epitaxial growth.

Tutelles UMR: UGA, CEA, CNRS, Grenoble-INP UGA

Fundings : ANR (ELMAX, NEXT), FLAG-ERA MNEMOSYN, PEPR SPIN (SPINMAT).

Collaboration : ESRF, SOLEIL Irig/MEM.

***Van der Waals-type two-dimensional (2D) materials*:** materials consisting of only one or a few atomic layers, in which the atoms are strongly bound within each layer, while the different layers are held together by much weaker van der Waals forces, allowing the layers to be separated or stacked and their number to be controlled down to a single atomic layer.

Spintronics*: a field of electronics that harnesses not only the electric charge of electrons but also their spin—a quantum property associated with their magnetic moment—to store, transport, or process information.

Ferromagnetic properties*: the ability of a material to exhibit spontaneous magnetization and to retain a portion of that magnetization when the external magnetic field is removed.

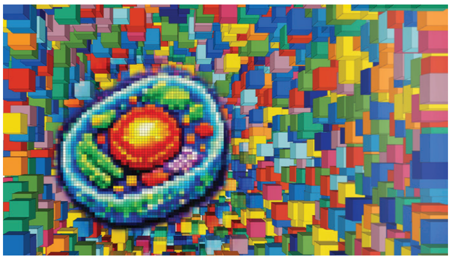
Molecular beam epitaxy*: a technique that involves directing a beam of atoms or molecules into a vacuum chamber, where they gradually deposit onto a substrate, causing ultra-thin crystalline layers to grow, layer by layer.

X-ray circular magnetic dichroism (XMCD)*: a technique that probes the magnetic properties of a material by enabling the visualization and characterization of magnetism at the atomic scale

REFERENCE
Courtin J. et al.
High Temperature Ferromagnetism in Epitaxial Monolayers of Co-Doped Fe_5GeTe_2
Physical Review Letters 2026

Toward "Gentle" X-Ray Fluorescence (XRF) Microscopy

Nicolas Vigano & Dmitry Karpov
Modeling and Exploration of Materials laboratory



Although X-ray fluorescence (XRF) microscopy is a gold-standard technique for mapping the chemical composition of samples at the nanoscale, obtaining high-resolution images and detecting elements present in very small quantities, it requires long acquisition times and high radiation doses. To overcome these limitations, a consortium of researchers from the ID16A beamline of ESRF and CEA-Irig/MEM in Grenoble has developed a "self-supervised" noise reduction method that significantly improves image quality.

XRF microscopy is an analytical technique that uses a focused X-ray beam combined with the detection of fluorescent X-rays emitted by excited atoms. By scanning the sample point by point, it provides quantitative maps of chemical elements with a resolution that can reach the nanometer scale; however, this requires long acquisition times and high radiation doses, which can be critical for radiation sensitive samples such as biological cells or **energy materials***. Multichannel detectors, offer a trade-off between data quality and sample preservation by collecting more photons and increasing the signal-to-noise ratio (SNR). However, the number of detectors that can be integrated is limited by their cost and available space. An alternative is to attempt to improve the SNR using computational noise reduction methods.

In this study, researchers developed a self-supervised denoising based on the **Noise2Noisemethod*** and the **U-Net architecture***. This method was initially tested on a sample with a known geometry ("**Siemens star***") and demonstrated a significant noise reduction in image without altering the geometry of the patterns or the quantification, even for a multi-element detector with only a few channels (2 to 4). The researchers subsequently validated this method on human cancer cells—a case representative of biological applications where it is imperative that radiation doses remain low—by showing that, based on fast acquisitions (10 ms per pixel), the resulting images, which were initially very noisy, are more readable, revealing structures that were obscured in the raw images, and are sharper than reference images acquired with five times longer exposure (50 ms per pixel).

The developed method enables obtaining images of comparable or even superior quality to those obtained through much longer exposure times, thus keeping the radiation dose low and acquisition time fast. This approach will therefore be particularly useful for mapping trace elements in radiation-sensitive biological samples, for characterizing materials requiring large-area analysis, and for time-resolved studies where acquisition speed is critical. Furthermore, to achieve this type of result, there is no need to use detectors composed of large number of detector elements, which means that this method can be implemented on existing XRF and EDX instruments without any hardware modifications

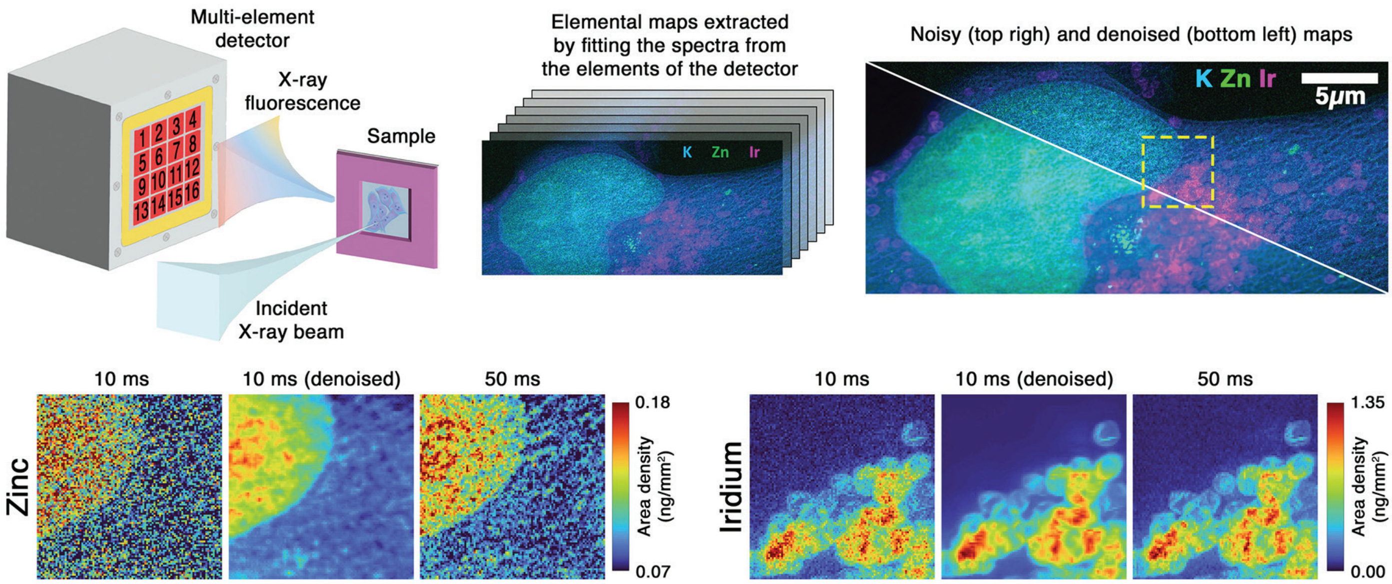


Diagram of the multi-element XRF detector arrangement alongside the denoising results. The panels compare raw data acquired at 10 ms per pixel, the denoised reconstruction, and a reference map recorded at 50 ms per pixel for Iridium and Zinc elemental lines. © CEA

Tutelles UMR : Univ. Grenoble Alpes, CEA, CNRS

Fundings : ESRF beamtime at ID16A (experiment IHLS-3625); EU Horizon 2020 MSCA COFUND ENGAGE (No. 101034267) & SCANnTREAT (No. 899549).

Collaborations : ESRF.

energy materials*: materials used to generate, convert, store, or conserve energy, such as for manufacturing battery electrodes and electrolytes or produce, store, or use hydrogen. They encompass also thin film photovoltaic materials or materials that can convert CO_2 into useful molecules, ...

Noise2Noise method*: a deep learning method that trains a denoising network using noisy images. Since noise is random and varies from one image to another, the network does not learn to reproduce the noise but gradually learns to identify the common element: the actual signal.

U-Net architecture*: a convolutional neural network* architecture originally developed for image segmentation and now widely used for image restoration tasks. Its structure allows the network to analyze an image at multiple scales and reconstruct it while preserving fine details.

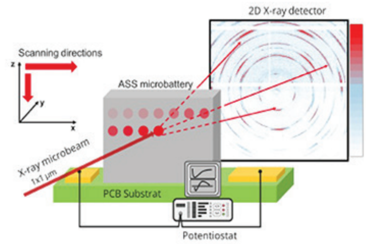
convolutional neural network*: a deep learning architecture that, through convolution operations, learns to recognize relevant structures in an image, thereby enabling denoising, segmentation, or restoration.

Noise2Noise method/U-Net-type architecture*: by treating the maps from the detector's individual channels as independent observations of the same underlying structure, pairs of images are generated and used to train a denoising model. A denoised image is then reconstructed by combining the outputs of the trained U-Net network.

Siemens star*: a resolution test target made of radial gold patterns deposited on a silicon substrate.

REFERENCE
Shishkov R, Laugros A, Vigano N, Bohic S, Karpov D, Cloetens P.
Self-Supervised Deep-Learning Denoising for X-ray Fluorescence Microscopy with Multi-Element Detectors
Analytical Chemistry 2026

Other scientific results



Operando synchrotron imaging of all-solid-state microbatteries

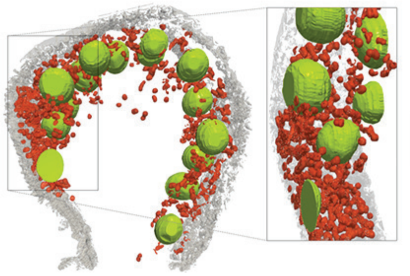
A consortium of researchers from CEA-Irig, CEA-Leti, and the European Synchrotron Radiation Facility (ESRF) has made a major breakthrough by conducting the first-ever X-ray monitoring of the entire operation of an all-solid-state microbattery.

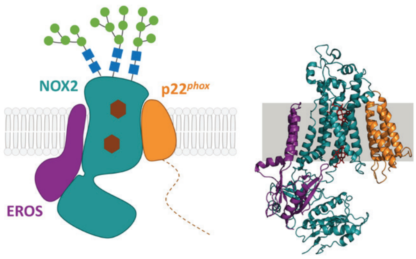
[***Read +***]

When symbiosis boosts photosynthesis and carbon storage in Microalgae

Researchers at CEA-Irig/LPCV have shown that microalgae living in symbiosis* with their host perform better than when they live on their own. Their photosynthesis is stimulated, allowing them to fix more CO_2 and produce more reserves in the form of starch and lipids.

[***Read +***]





EROS the hidden hero of antimicrobial defense

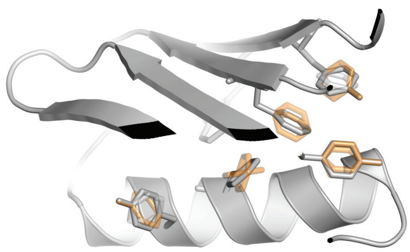
Our immune system relies on specialized cells, such as neutrophils and macrophages, to detect and eliminate invading microbes. One of the most powerful weapons used by these cells is a multicomponent molecular machinery known as NADPH oxidase.

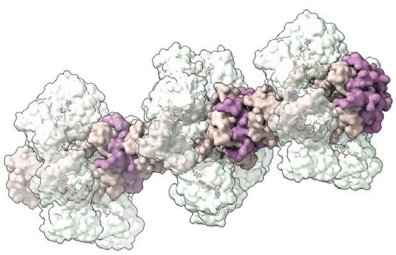
[***Read +***]

How the environment shapes protein dynamic

A study published in Nature Chemistry investigates how the environment reshapes protein conformational energy landscapes using the model protein GB1.

[***Read +***]



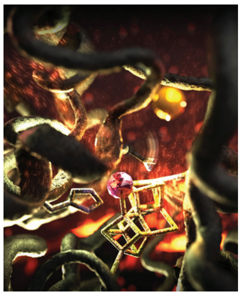


A novel tubular architecture sheds light on bacterial respiration

Respiration lies at the heart of energy conversion in most living organisms. It relies on electron transfer chains located in the membrane, where small molecules called quinones act as electrochemical shuttles.

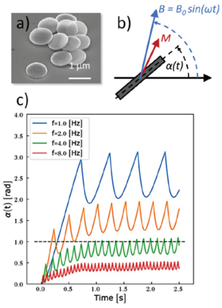
[***Read +***]

Structural snapshot of biological nitrogen fixation in hell



Although nitrogen gas composes up to 78% of Earth's atmosphere, its triple bond makes it hard for organisms to use. To do so, microbes perform the remarkable reaction of nitrogen fixation—converting N_2 into the fertiliser and biofuel ammonia, while participating in Earth's nitrogen cycle.

[Read +]

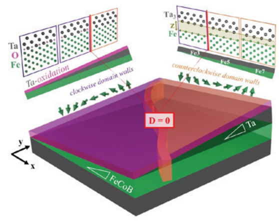


Magnetic vortex micro-disks dynamics in viscoelastic environments

Magnetically driven microparticles provide a versatile platform for probing and manipulating biological systems. Yet the physical framework governing their actuation in complex environments remains only partially explored.

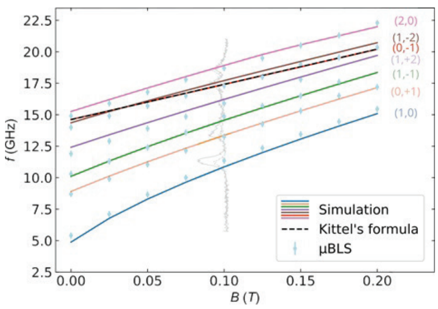
[Read +]

Dzyaloshinskii-Moriya interaction chirality reversal with ferromagnetic thickness



In Ta/FeCoB/TaOx, it was demonstrated that the Dzyaloshinskii-Moriya interaction (DMI) chirality can undergo modification solely in response to variations in the thickness of the ferromagnetic layer.

[Read +]

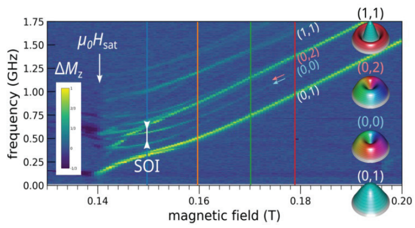


Spin waves in cylindrical magnetic conduits: from theory to experiment

Spin waves are propagating fundamental excitations of magnetic systems, also carrying promises for low-power logic and data transfer. We report the measurement of thermal spin-wave spectra in single cylindrical nanowires, and their quantitative analysis as modes with a radial and azimuthal index.

[Read +]

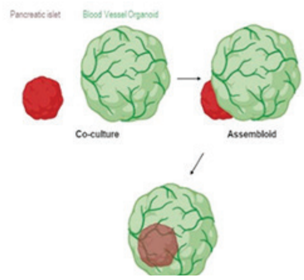
E pur si muove! And yet it moves!



Angular momentum (AM) is the conserved quantity associated with rotational invariance. Harnessing its orbital component in axi-symmetric sample is often challenging. Interestingly, we show that azimuthal spin waves in normally magnetized disks are largely immune to imperfections that would otherwise prevent the wavefront from orbiting around the disk.

[Read +]

Type 1 diabetes: pancreatic islet vascularisation on-chip



Within the framework of the FOCUS OSP and ANR JCJC ATOP1 projects, researchers from CEA-Irig/BGE/BIOMICS recently demonstrated that co-culture of a pancreatic islet* with a blood vessel organoid* leads to the fusion of these two three-dimensional (3D) structures, forming what is known as an 'assembloid'.

[Read +](#)

A dual-function protein orchestrates flowering

The transition from the vegetative phase to the reproductive phase in flowering plants (angiosperms) is marked by the bloom shift . This transition is finely controlled by the ULTRAPETALA1 protein, which regulates the expression of key genes involved in the flowering and floral morphogenesis.

[Read +](#)

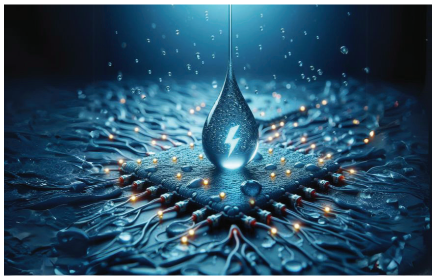
Prizes - Media

Alexandra Colin and Nicola Galvanetto, awarded «ERC Starting Grant» 2026

ERC Starting Grants, awarded by the European Research Council, offer brilliant young researchers the opportunity to carry out innovative projects with great promise for the future. This funding will enable them to successfully complete their projects and establish their own research teams.

[Read +](#)

AMYLEN, Winner of the “Out of Lab” Grand Prize - Anima



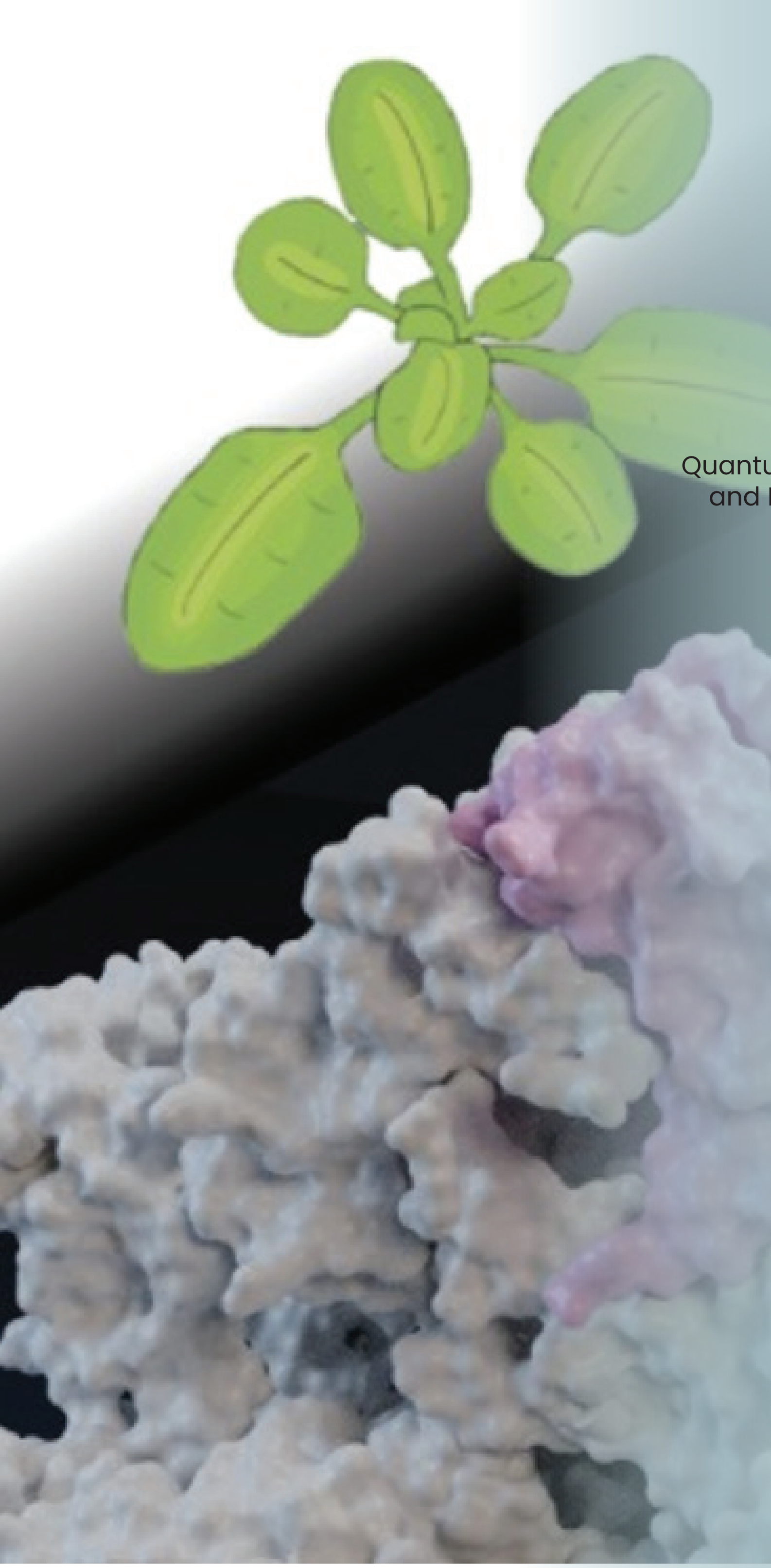
The « Out of the Lab » Grand Prize, a competition organized by [Anima](#), was awarded to the AMYLEN project—a bio-inspired generator based on marine-derived biomaterials capable of continuously converting ambient humidity into electricity without requiring any infrastructure or rare materials!

[Read +](#)

Oleksandra Yeromina, Winner of the 2026 i-PhD Award for QDLab, a SWIR Project Incubated in Magellan

Oleksandra Yeromina, a researcher at CEA-IRIG/SYMMES, was awarded for her QDLab project, which has been incubated since March 2025 in the CEA’s Magellan program. This project aims to revolutionize optical detection in the short-wave infrared (SWIR, 1–2.5 µm).

[Read +](#)



Quantum Photonics, Electronics and Engineering laboratory
CEA-UGA
www.Pheliqs.fr

Biology and Biotechnology for Health Laborator
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www.Biosante-lab.fr

Spintronics and Technology of Components laboratory
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