World-class research for our daily lives

TACKLING SOCIETAL CHALLENGES AT ACCELERATOR-BASED PHOTON SOURCES

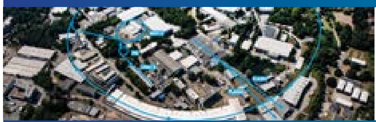
LEAPS League of European Accelerator-based Photon Sources

LEAPS FACILITIES

The League of European Accelerator-based Photon Sources, LEAPS, is a strategic consortium of 19 synchrotron radiation and free electron laser user facilities across Europe. Their core mission is to elevate the quality and influence of fundamental, applied, and industrial research at each facility, amplifying the benefits for European science, innovation, and society as a whole.

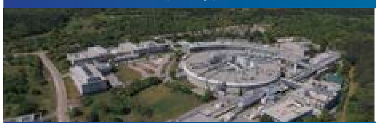
ALBA - Barcelona (Spain)

DESY - PETRA III and FLASH - Hamburg (Germany)

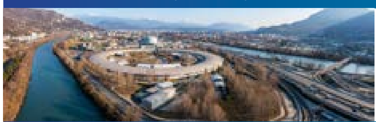


Diamond Light Source - Didcot (United Kingdom)

Elettra - Trieste (Italy)

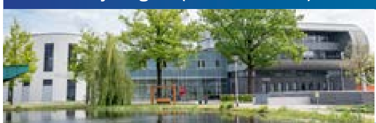


ESRF - Grenoble (France)



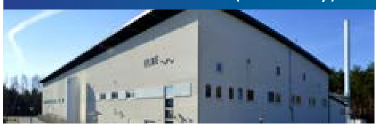
European XFEL - Schenefeld (Germany)

FELIX - Nijmegen (Netherlands)



HZB - BESSY II - Berlin (Germany)

HZDR - ELBE - Dresden (Germany)



INFN - Rome (Italy)

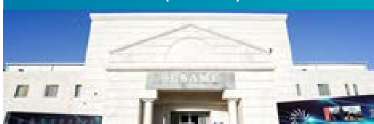
ISA - ASTRID2 - Aarhus (Denmark)

MAX IV - Lund (Sweden)

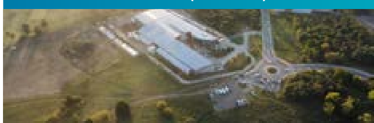
PSI - SLS and SwissFEL - Villigen (Switzerland)

PTB - Metrology Light Source - Berlin (Germany)

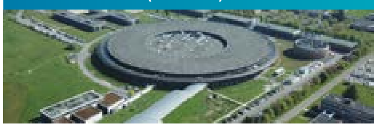
SESAME - Allan (Jordan)



SOLARIS - Krakow (Poland)



SOLEIL - Paris (France)



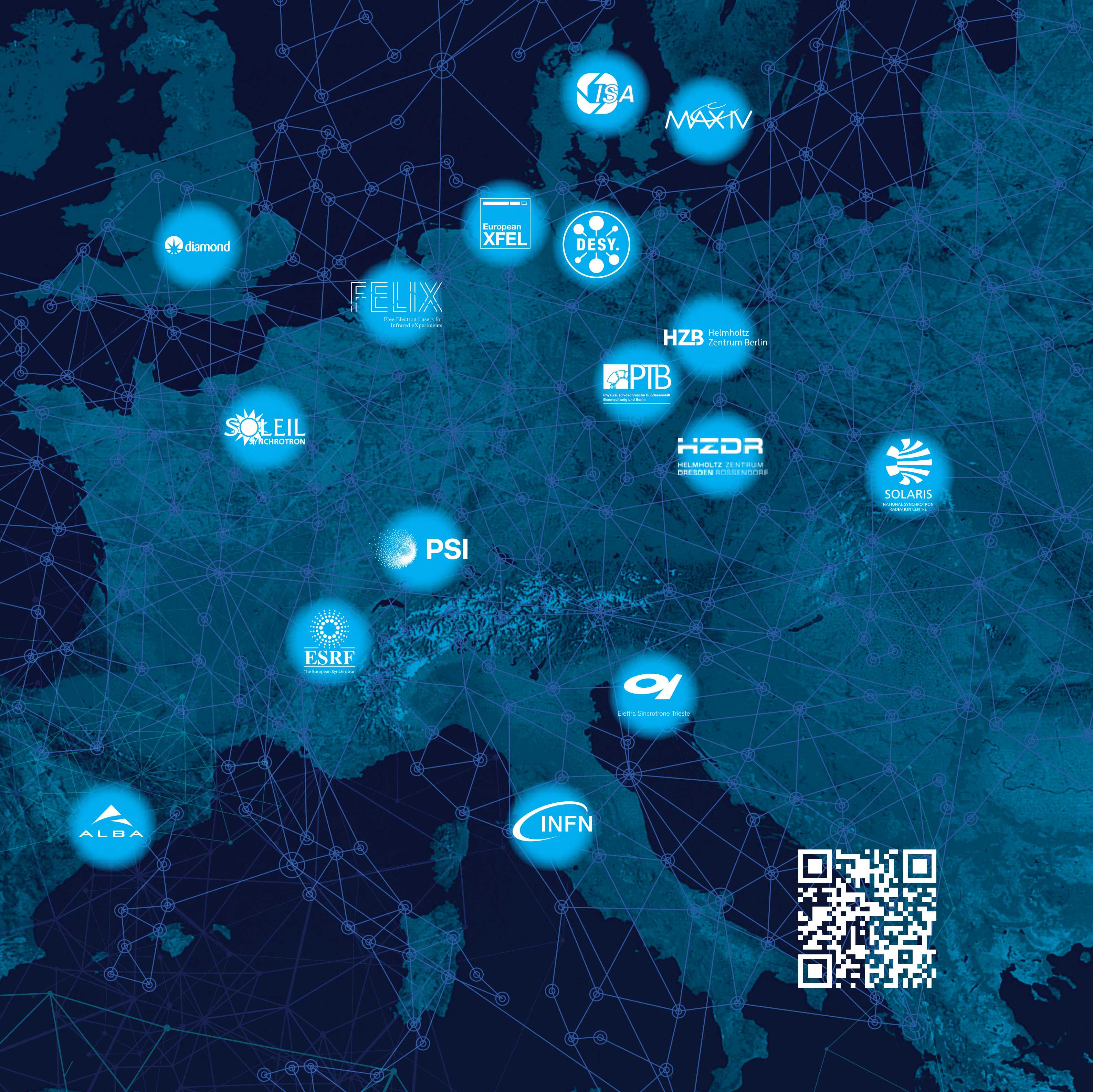
Together we are a catalyst for European research

Vision

A world where European science is a catalyst for solving global challenges, a key driver for competiveness and a compelling force for closer integration and peace through scientific collaboration.

Mission

LEAPS will use the power of its combined voice to ensure that member light source facilities continue to be world - leading, to act as a powerful tool for the development and integration of skills with a view to address 21st century global challenges, and to consolidate Europe's leadership in the field.



RESEARCH FOR THE BENEFIT OF SOCIETY

On the following pages, you will discover a selection of research breakthroughs and innovative projects using one or sometimes several European accelerator-based photon sources. These facilities are inherently multi- and interdisciplinary, uniting scientists worldwide across diverse fields such as physics, chemistry, energy research, information technology, medicine, biology, environmental science, food security, and cultural heritage.

Accelerator-based photon sources play a crucial role in addressing grand challenges, by supporting applied research for today's needs and fundamental science for tomorrow's advancements.

Over 107 000 publications in the past decade showcase our facilities' immense global impact. In Europe, LEAPS stands out in the scientific community, with more than 30 000 scientists from 93 countries utilising its 19 facilities. They work hand in hand with national user organisations and the European Synchrotron and Free Electron Laser User Organisation (ESUO).[1]

The LEAPS consortium recently developed a new European strategy for collaboration over the next decade.[2] The goal is to stay at the forefront of finding solutions to current and future challenges in research and innovation. This strategy aims to position Europe as a global leader in key technologies for the future.

Together we are stronger
Together we work on solutions

[1] https://www.esuo.eu/
[2] https://link.springer.com/article/10.1140/epjp/s13360-023-03947-w

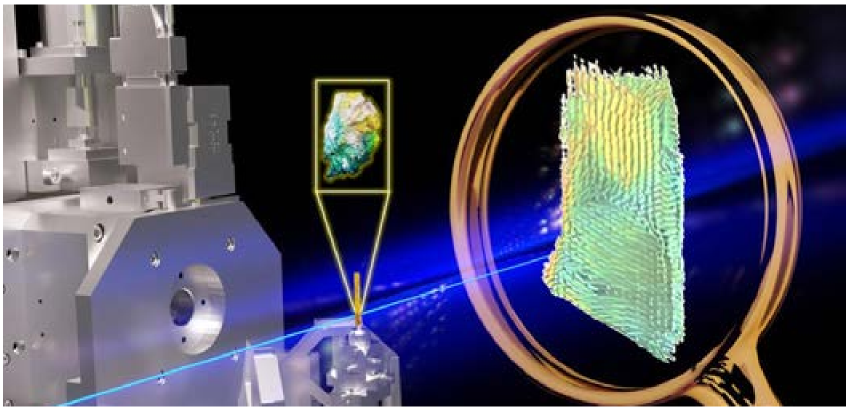
CONTENT

HEALTH

The latest United Nations report projects the world population to reach 9.6 billion by 2050, with the number of people aged 60+ expected to double. Addressing health challenges requires substantial commitment, from basic research and new treatments to preventive healthcare.

Researchers are also tackling these issues at accelerator-based photon sources in Europe contributing to the development of new treatments, understanding diseases and improving drug design, driving innovation in healthcare.

Breast cancer: understanding it to treat it



Credit: S. Haas, DESY

Breast cancer caused 670 000 deaths globally in 2022[3] according to the WHO. It is not life-threatening in its earliest form, but if the cancer cells are able to spread further throughout tissue to nearby lymph nodes or to important organs, this metastasis can be fatal. An international collaborative effort between researchers from different types of institutions has yielded a cutting-edge multimodal imaging approach to investigating breast cancer tissue. This research not only advances the understanding of breast cancer metastasis but also emphasises the relevance of developing novel therapeutic strategies in neurosurgical oncology.[4]

Early detection of Pyridoxine-Dependent Epilepsy in newborns

Credit: Rainer Mairores, Pixabay

Pyridoxine-dependent epilepsy (PDE) is an inborn error of metabolism that results in severe epilepsy in newborns. Ideally, early detection in newborn screening would allow for the earliest correct diagnosis. Conventional methods offer no way of identifying biomarkers that could be used for its detection. However, a previously unknown human metabolite was identified as a highly diagnostic compound suitable for newborn PDE screening protocols using Infrared Ion Spectroscopy.[5]

[3] https://www.who.int/news-room/fact-sheets/detail/breast-cancer
[4] https://doi.org/10.1038/s41598-024-51945-4
[5] https://doi.org/10.1172/JCI148272

Towards preventing diabetes

Credit: T. Ursby, MAX IV

An enzyme called urocanate reductase, which occurs in the bacteria found in the human gut, breaks down urocanic acid, a natural constituent of skin and other tissues of the body, into the metabolic product imidazole propionate. This metabolite has been linked to diabetes and other diseases. A team of researchers investigated the molecular structure of the enzyme to find possible ways to inhibit it and prevent imidazole propionate production of the diabetes related metabolite.[6]

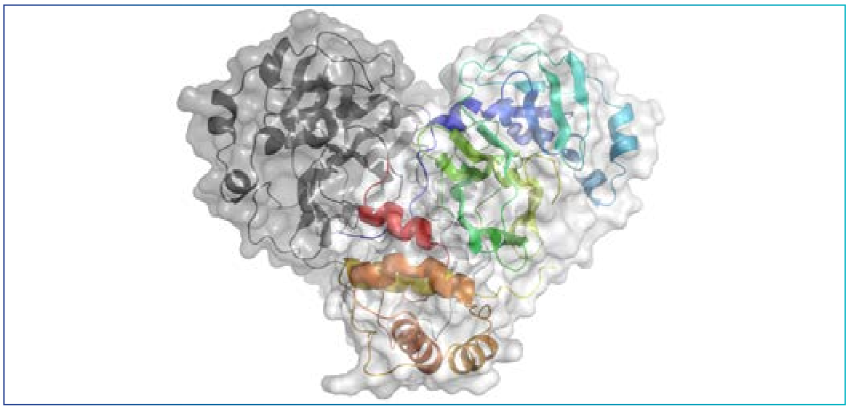
Reversing muscular dystrophy

Credit: © Adobe Stock

Congenital muscular dystrophy is a rare minority disease that can lead to a high level of disability and low life expectancy. It mainly affects children and has no treatment. A study promoted by a patients' association, in collaboration with a children's hospital in Barcelona literally shed light on the alterations in cells caused by the disease and proved how an experimental treatment with gene therapy helps to reverse these defects.[7]

[6] https://www.maxiv.lu.se/article/one-step-towards-prevention-of-diabetes-linked-substance-produced-by-the-human-gut-microbiota-first-user-experiment-at-micromax/
[7] https://www.mdpi.com/1422-0067/23/14/7651

Globally affordable antiviral drugs



Cartoon representation of the SARS-CoV-2 dimer with a semi-transparent surface in grey.
Credit: Diamond Light Source Ltd

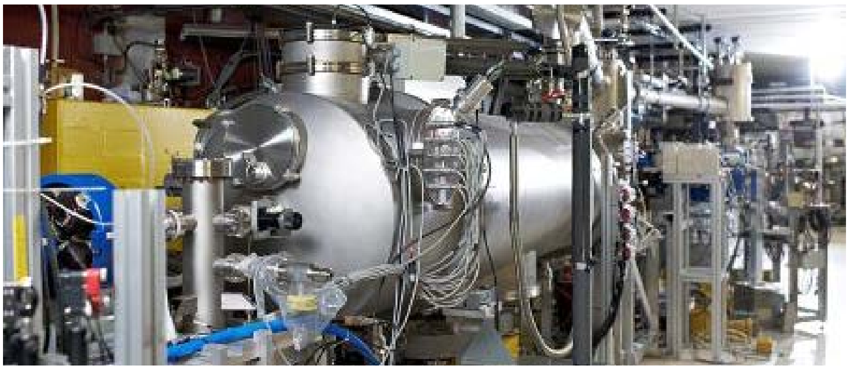
An unprecedented crowdsourced and fully open collaboration of more than 200 scientists including a photon source rapidly identified and developed novel compounds that have excellent antiviral activity against a key enzyme of the SARS-CoV-2 virus, namely its main protease (Mpro), which is involved in the reproduction of the virus. The lead drug candidate is now in pre-clinical evaluation.[10]

The three-dimensional architecture of Mpro was decoded as early as March 2020. Analysing its 3D architecture allows the systematic development of drugs that inhibit the reproduction of the virus.[11]

COVID-19

In the first year of the COVID-19 pandemic, there was on average one Corona-related publication from a synchrotron light source every fifth day.[8] At that time, the relevance of the LEAPS consortium became particularly visible, as all LEAPS facilities made available their experimental stations to virologists and hospitals for precision structural analyses.[9]

Producing medical isotopes without nuclear fission



Credit: J. Jeibmann, HZDR

In a collaboration with the Dutch company Demcon, a 30 kilo-watt electron beam was focused on a tiny volume of material for one week, non-stop. The energy deposited, comparable to that of a Boeing 747 travelling at 900 kilometres an hour, resulted in the production of molybdenum-99, which decays into technetium-99m. This isotope is commonly used for imaging in the treatment of cancer patients. The innovative isotope production method avoids the need to split uranium in nuclear reactors, thereby reducing radioactive waste and offering potential scalability for industrial use.[12]

[8] https://lightsources.org/2021/12/14/lightsource-research-and-sars-cov-2/
[9] https://leaps-initiative.eu/wp-content/uploads/2020/05/LEAPS_fighting_COVID19_May2020.pdf
[10] https://www.nature.com/articles/s41467-023-37035-5
[11] https://www.science.org/doi/10.1126/science.abb3405
[12] https://www.hzdr.de/db/Cms?pOid=65365&pNid=3438

Driving drug discovery: the impact

Credit: © Adobe Stock

Since its inception, AstraZeneca Gothenburg has used synchrotron facilities for respiratory, cardiovascular and renal disease research, enabling high-resolution structure resolution of drug candidates. Accessible remotely and often fully automated, synchrotrons simplify sample submission and data retrieval. Previously operating its own X-ray facilities, in 2019, AstraZeneca chose synchrotrons for superior data quality and accessibility. Now, it solely relies on them for crystallographic drug research. Many asthma and cardiovascular drug candidates explored here are in clinical trials. By leveraging synchrotron facilities, AstraZeneca has enhanced its discovery pipelines, leading to the discontinuation of its in-house X-ray source. This underscores the LEAPS programme's comprehensive support to industries across sectors, the constant strengthening of the European light sources cooperation and the implementation of new innovative strategies.

ENERGY

Our society needs sustainable technologies to bring our energy supply and material cycles into a coherently connected low-carbon economy. Solar power is an important driver of the transition to a sustainable, carbon-neutral society. Making clean electricity available in periods of low solar irradiation is just as important and, in this respect, chemical energy conversion takes centre stage with hydrogen and batteries in the leading roles.

Not only will power-to-gas and power-to-fuel replace fossil fuels; producing them even consumes carbon dioxide from the atmosphere. All options to increase sustainability in the global energy supply must be explored.

Cheaper and more efficient solar cells

Credit: © Adobe Stock

For the first time, a low-cost silicon solar cell technology has surpassed the 30% efficiency milestone. Studies demonstrated an efficiency of 31.25% by stacking silicon and perovskite cells in a so-called tandem structure, exceeding the efficiency of the best commercial cells by 28%.[13] On their own, silicon solar cells used for solar electricity are limited in terms of their achievable efficiency (around 24.5% for commercial cells, 27% in laboratory settings, and 29% in theoretical calculations).

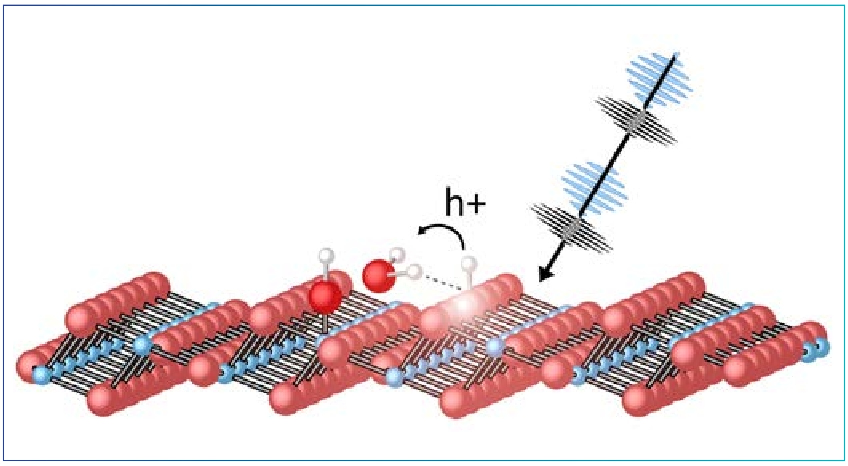
Flexible cost-effective solar cells

Credit: © Adobe Stock

Cost-efficient and flexible solar cells are one of the pillars of the carbon-neutral economy. Novel, all-organic solar cells are promising candidates for real-world applications. In order to identify the bottlenecks for the efficiency of these devices, an international team used ultra-short X-ray pulses and found a new and fast channel for mobile charge carrier generation. These carriers are the principle actors in photovoltaic devices.[14]

[13] https://www.science.org/doi/10.1126/science.adg0091
[14] https://www.nature.com/articles/s41467-021-21454-3

Photocatalytic water splitting in real-time



Credit: DESY

An international team studied the hydrogen bonding of water molecules on a photocatalyst as well as the first steps of their complex reaction pathways. To optimise the given technologies, it is crucial to break the complex process systematically down into its individual, ultrafast reaction steps. The data from that first view, femtoseconds after light activation of the catalyst/water system, provides valuable information essential for a range of catalytic reactions in real-world aqueous operating conditions.[15]

Energy storage

Sustainable electricity that is generated from photovoltaics or wind but is not directly used must be stored in order to guarantee a secure energy supply 24/7. Electrochemically splitting water into oxygen and hydrogen holds great potential in leading to a green hydrogen economy.

Splitting seawater

Credit: © Adobe Stock

Hot, arid regions or deserts with intense solar irradiation are ideal locations for photovoltaics. However, their defining characteristic is their lack of fresh water. A group of scientists investigated catalysts that allow direct splitting of seawater and, with it, the use of this vastly more abundant and effectively inexhaustible raw water resource.[16]

[15] https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.130.108001
[16] https://onlinelibrary.wiley.com/doi/10.1002/aenm.201800338

Synthetic aviation fuels, synthetic cooking gas

Credit: © Adobe Stock

The CARE-O-SENE[17,18] project aims to develop highly efficient Fischer-Tropsch catalysts for transforming the aviation sector. Meanwhile, GreenQUEST[19] is a global initiative focused on producing a scalable green version of the existing fossil fuel liquefied petroleum gas, aiming to establish best practices in policy, technical standards, safety, and market/business structures that can be shared globally. Both projects are speeding up innovation cycles by combining industrial technology development with a fundamental understanding of the end product; here, synchrotron radiation is being used as a powerful tool to study the molecular and atomic structure of materials, enabling targeted and efficient development and optimisation of new materials needed to address the current challenges of the energy transition.

Green hydrogen

Hydrogen can be seen as the first link in a long and branched chain. Transporting hydrogen without risks bound in molecules or further processing it with carbon dioxide to produce sustainable chemicals requires the understanding and optimisation of catalytic reactions.

[17] https://care-o-sene.com/en/care-o-sene/
[18] https://www.helmholtz-berlin.de/pubbin/news_seite?nid=24135;sprache=en
[19] https://www.helmholtz-berlin.de/pubbin/news_seite?nid=26646&sprache=en&seitenid=1

Lithium-free and novel batteries

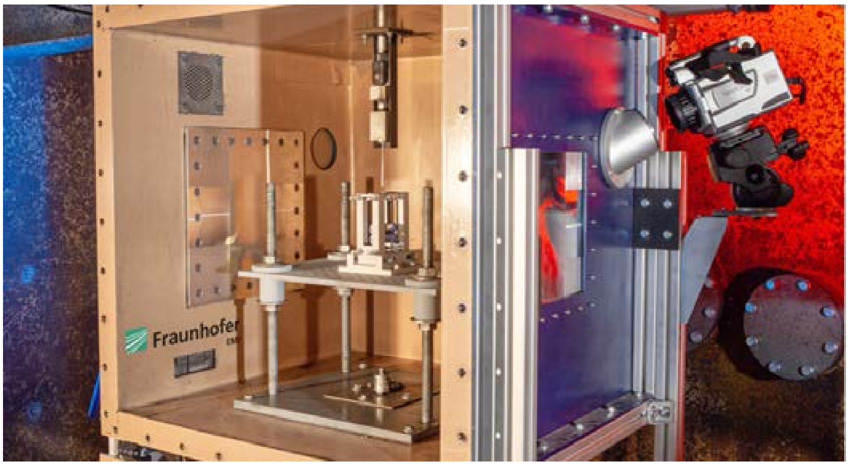
Credit: © Adobe Stock

With increasing electricity consumption, especially in electromobility, demand for battery capacity has been developing at a high pace. For Lithium-ion batteries alone, an increase from 700 in 2022 to 4700 gigawatt hours by 2030 is expected.[20]

The LEAPS Consortium strongly supports the **European "BATTERY 2030+" Roadmap**.[21] All LEAPS facilities are seeing a steep rise in demand from the battery research community and growing interest from industry. Lithium-free batteries[22], redox-flow batteries, and novel battery materials[23] are in the focus for the next generation of energy storage based on rational design and for promoting the transition of our societies towards fossil-free energy supplies.

[20] https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/battery-2030-resilient-sustainable-and-circular
[21] https://www.leaps-initiative.eu/resources/
[22] https://www.sciencedirect.com/science/article/pii/S2095927322006004?via%3Dihub
[23] https://www.nature.com/articles/s41467-023-36842-0

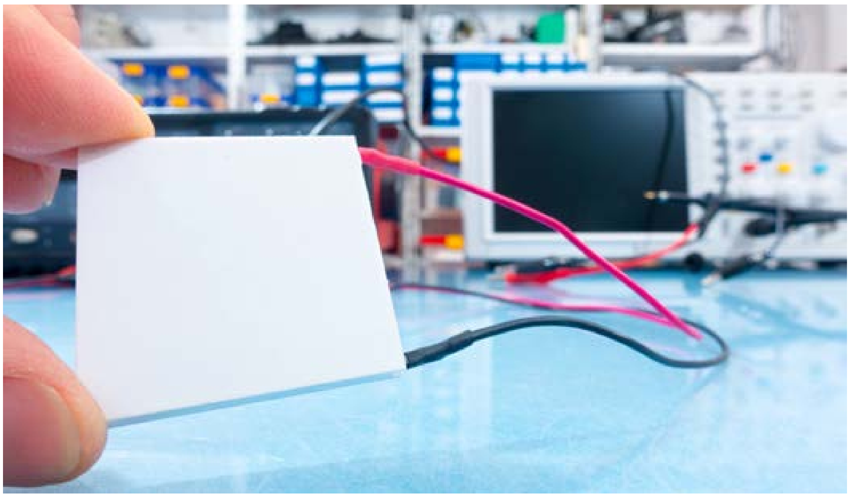
Improving battery safety



Credit: ESRF

Energy storage stands as a cornerstone technology in the 21st century, driven by the surge in electric vehicles and imperative carbon emissions reduction. However, a wide acceptance of new technologies entails trust in their safety. The Fraunhofer Ernst Mach Institute has pioneered a robust battery-abuse testing chamber facilitating safe exploration through diverse techniques including high-speed X-ray imaging. This innovative chamber fosters a deeper comprehension of battery failures and the validation of safety mechanisms with wide-reaching benefits for academia and industry alike.[24]

Towards green conversion of heat to electricity


Credit: © Adobe Stock

The thermoelectric effect allows direct conversion of heat into electricity without by-products like carbon dioxide emissions. Unfortunately, the efficiency of the process is relatively low, and the state-of-the-art commercially used materials are complex lead compounds. Tin selenide, SnSe, and its close relatives make a promising alternative with a simple, non-toxic composition.[25]

[24] https://journals.iucr.org/s/issues/2023/01/00/ye5024/index.html
[25] https://onlinelibrary.wiley.com/doi/10.1002/adom.202302049

ENVIRONMENT

Understanding environmental issues like pollution, climate change, and land restoration is key to protecting human health and preserving ecosystems. There's a growing need for long-term solutions to these challenges. To tackle them, advanced techniques are needed to study materials in areas like microbiology, geology, and geochemistry.

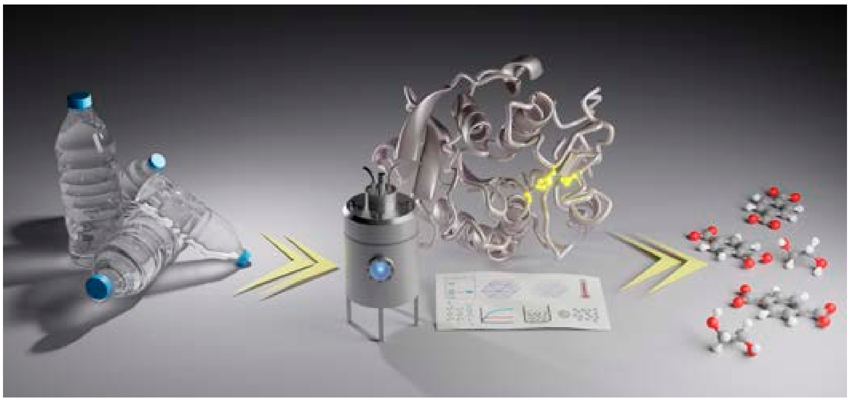
LEAPS facilities are uniquely equipped to support complex, cutting-edge research, offering valuable insights into environmental problems and contributing to the development of effective solutions.

Harvesting water in arid regions

Credit: © Marieh Al-Handawi, NYUAD 2023

The Athel tamarisk tree captures water in arid environments, and the adaptive mechanism of this desert bush can potentially inspire advanced water-harvesting technologies. A team from the New York University Abu Dhabi in United Arab Emirates and the Max Planck Institute for Solid State Research in Stuttgart (Germany) studied the ion-rich droplets on its leaves, which crystallise into salts and can harvest atmospheric moisture even at relatively low humidity levels. This hygroscopic salt mechanism for collecting moisture is a unique biological adaptation and suggests potential applications in creating eco-friendly materials for air moisture harvesting and cloud seeding.[26]

Soon more plastic than fish in the oceans?



Credit: © F. Lennartz and G. Weber, HZB

Over the last 80 years, about 10 billion tons of synthetic polymers (plastics) have been synthesised. Plastics are indispensable for us. However, waste mismanagement, resource-demanding recycling processes, and material complexity have led to a global plastic pollution problem: micro- and nanoplastic particles are now omnipresent, even in the remotest of places. Viable options for remediating this alarming scenario are enzymes and biotechnology for recycling and upcycling synthetic polymers. Working on PET ("bottle plastic") and polyurethane, research at synchrotrons is helping to expand our knowledge about the structures of these enzymes, and paving the way for their biotechnological improvement.[27]

[26] https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.130.108001
[27] https://onlinelibrary.wiley.com/doi/10.1002/aenm.201800338

Nanoplastics everywhere

Credit: Picture from public domain

Nanoplastics (NPs) are very alarming pollutants that can be present in food and water, and their frightening effects on our health when they penetrate into human cells are still far from being understood. X-ray and Fourier-Transform Infra-Red synchrotron studies show that NPs appear distributed mostly around the cellular outer edge, causing an increased production of triacylglycerols. These results indicate that NPs mostly affect lipid response, revealing further details of the real toxicological impact on the cells when people experience long-term exposure.[28]

Greener solutions, environmentally friendly production of chemicals

Credit: AI generated with Dall-e3

Industry relies on chemicals for a vast range of products, including starting materials for synthesising polymers and additives for use in plasticisers, lubricants, emulsifiers, and stabilisers. Many chemical synthetic approaches require suitable chemical catalysts that work under relatively harsh reaction conditions. To attain carbon-neutral emissions, it is necessary to develop alternative, greener technologies for the synthesis of chemicals. Research conducted at synchrotrons is paving the way for utilising enzymes in these processes. Ultimately, this will lead to environmentally friendly starting materials for a wide range of consumer products such as lubricants, textiles, soaps, and pharmaceuticals.[29]

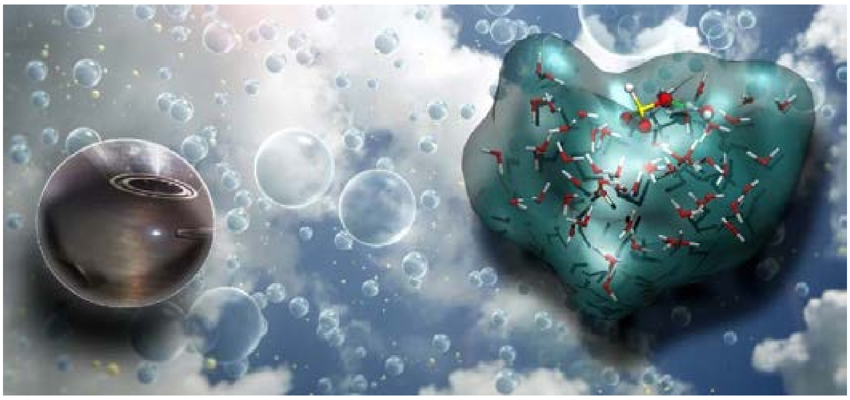
[28] https://www.frontiersin.org/journals/immunology/articles/10.3389/fimmu.2023.1247747/full
[29] https://pubs.acs.org/doi/10.1021/acssuschemeng.3c05867

Towards transforming the greenhouse gas methane into a less harmful chemical

Credit: E. Weckert

Methane, one of the most potent greenhouse gases, is being released into the atmosphere at an increasing rate by livestock farming as well as the continuing unfreezing of permafrost. Transforming methane and longer-chain alkanes into less harmful and in fact useful chemicals would remove the associated threats, and in turn make available a huge feedstock for the chemical industry. However, transforming methane necessitates as a first step the breaking of a C-H bond, one of the strongest chemical linkages in nature.
Short flashes of X-ray light both from FEL and synchrotron revealed for the first time how carbon-hydrogen bonds of alkanes break and how the catalyst works in this reaction. This brings scientists closer to developing better catalysts to transform methane into a less harmful chemical.[30]

Revealing the molecular origins of air pollution



Credit: FHI/MPG

A team of researchers at the Fritz Haber Institute of the Max Planck Society in Berlin, the Qatar Environment and Energy Research Institute/Hamad Bin Khalifa University, the Sorbonne University in Paris, the ETH Zurich, and several synchrotrons in Europe have made a groundbreaking discovery in understanding how air pollution forms at the molecular level.
This investigation sheds light on the complex chemical processes occurring at the boundary between liquid, in particular aqueous solutions, and vapor in our atmosphere. Understanding these processes is crucial for developing strategies to reduce air pollution and its harmful effects on health and the environment.[31]

[30] https://www.science.org/doi/10.1126/science.adf8042
[31] https://doi.org/10.1038/s41467-024-53186-5

FOOD

As global costs rise and demand for local food supplies grows, sustainability and waste reduction have become critical priorities for the industry. In response to food safety concerns, consumers now expect higher standards of quality control and traceability, which are crucial in a competitive market where new products are constantly emerging.

Innovation in this field requires a multidisciplinary approach, a solid understanding of the science behind products and processes, and access to a wide range of research and development tools.

How much cadmium is contained in cocoa beans?

Credit: © Adobe Stock

Cocoa beans can absorb toxic heavy metals such as cadmium from the soil. It is known that cultivation areas can be polluted with these heavy metals, and in some cases considerably so. Synchrotron studies allowed to measure non-invasively exactly where cadmium accumulates in cocoa beans: it turns out this is mainly in the shell. Further investigations show that the processing of cocoa beans can have a great influence on the concentration of heavy metals.[32]

Whiter than white - the banning of E171 from food

Credit: Luis Aguila, Unsplash

Titanium dioxide, TiO_2, is used as a white colouring and opacifier in many products, including food (candy, gum, ...). Researchers studied at a synchrotron tissue samples from rats that, over a period of 100 days, ingested an amount of E171 proportional to the average human consumption. TiO_2 was found in the rats' liver. Immune system disorders and precancerous colon lesions were also observed.[33]

Following the publication of the first study in January 2017, the French Agency for Food Safety is notified and several candy manufacturers decide to stop using E171 in their production. In April 2019, the French government announces a total ban of E171 from food production starting 1 January 2020. In 2022, it was banned as an additive in foods in the whole of the European Union.[34]

[32] https://pubs.acs.org/doi/10.1021/acs.analchem.2c05370
[33] https://www.synchrotron-soleil.fr/en/news/soleils-contribution-whats-our-plates
[34] https://food.ec.europa.eu/food-safety/food-improvement-agents/additives/re-evaluation_en#questions--answers-on-titanium-dioxide

Healthy and tasty

Credit: Mike Kenneally, Unsplash

Fibre-rich foods might be relatively unpopular choices because they are not as soft and tasty as products containing less fibre. If the fibre is extracted out of the hard and chewy bran, the outer part of the wheat kernel, they can be added to the product without being noticed as much. At present the process is, however, not effective, and a significant amount of fibre is left behind. Swedish agricultural cooperative Lantmännen used synchrotron radiation to develop a better process.[35]

Waste of viticulture for pest control

Credit: Pexels

Researchers from Universidad de Castilla la Mancha, Universidad Autónoma de Madrid and the Institute of Agricultural Sciences proved the potential of wine production residues as biopesticides in agriculture, thus reducing the waste management problem and contributing to a circular economy. Their work shows that recycled biochar from grape pomace is effective to reduce the parasitic nematode infection of tomato plants in pots.[36]

[35] https://www.maxiv.lu.se/article/lantmannen-investigating-wheat-bran-for-better-tasting-fibre/
[36] https://link.springer.com/article/10.1007/s42773-023-00228-8

INFORMATION TECHNOLOGY

Humans have been storing, retrieving, manipulating, and sharing information since the first writing systems were created. Today, Information Technology covers computer systems, software, programming languages, data processing, and digital storage.

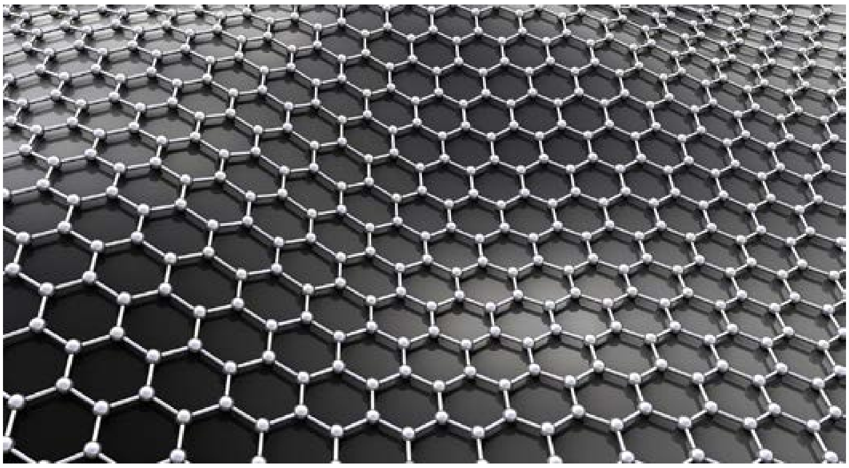
By studying how materials behave at various stages of degradation, LEAPS facilities can reveal the connection between their microstructure, degradation, and mechanical performance. This knowledge allows for the intentional design of microstructures with specific properties, driving further innovation.

Synchrotron light in every mobile phone

Credit: PTB

Developments in the semiconductor industry have significantly changed the world over the decades. This trend follows Moore's Law, which states that the complexity of integrated circuits increases exponentially while costs are minimised. This places permanently high demands on technology developers. For more than 20 years, synchrotrons have been supporting the development of extreme-ultraviolet light (EUV) projection optics, in particular with the world market leader in lithography steppers ASML and its German partner Carl Zeiss through at-wavelength metrology with synchrotron radiation.[37]

Graphene has paved the way



Credit: iStock

Two hundred times more resilient than steel but six times lighter, ultra-flexible, a remarkable heat conductor, almost transparent: the potential applications of graphene are many and varied, ranging from extremely solid materials to photovoltaic cells and, most of all, electronics. An outstanding electrical conductor, graphene has emerged as an exciting alternative to conventional silicon-based semiconductors. To confirm the theoretical predictions made about this unique material and to test and validate various manufacturing processes, graphene properties have been extensively studied at synchrotrons.[38]

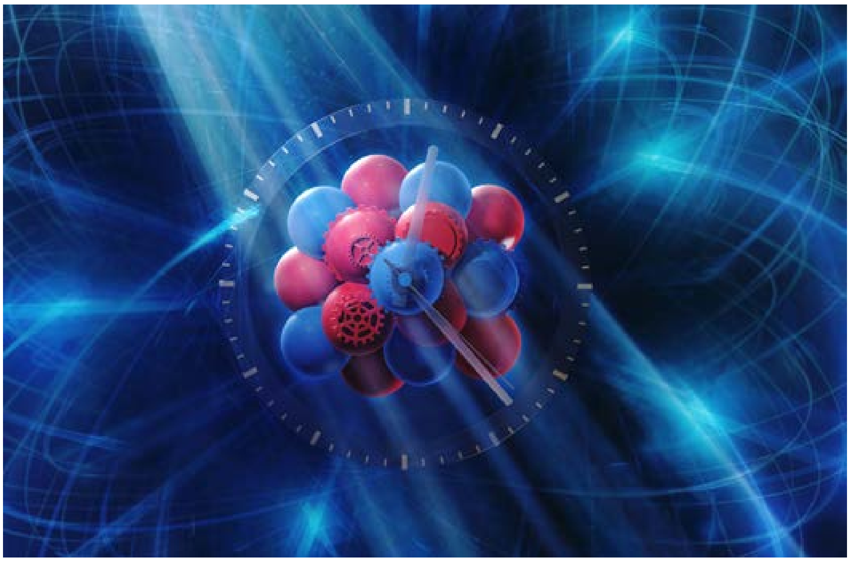
[37] https://link.springer.com/article/10.1140/epjp/s13360-022-03417-9
[38] https://www.synchrotron-soleil.fr/contributions/QuantumMaterials/

Reducing energy consumption in hard drives through all-optical switching

Credit: M. Geissinger, FELIX

Information and communication technologies currently account for 7% of global energy production, and the demand for higher data storage capacities continues to rise. This makes developing novel, less energy-intensive technologies for hard-disk drives all the more crucial for reducing global energy consumption. The realisation of all-optical switching by using short and intense pulses from a free electron laser is a groundbreaking advancement in this field, paving the way for more energy-efficient data storage solutions.[39]

Milestone for new nuclear clocks

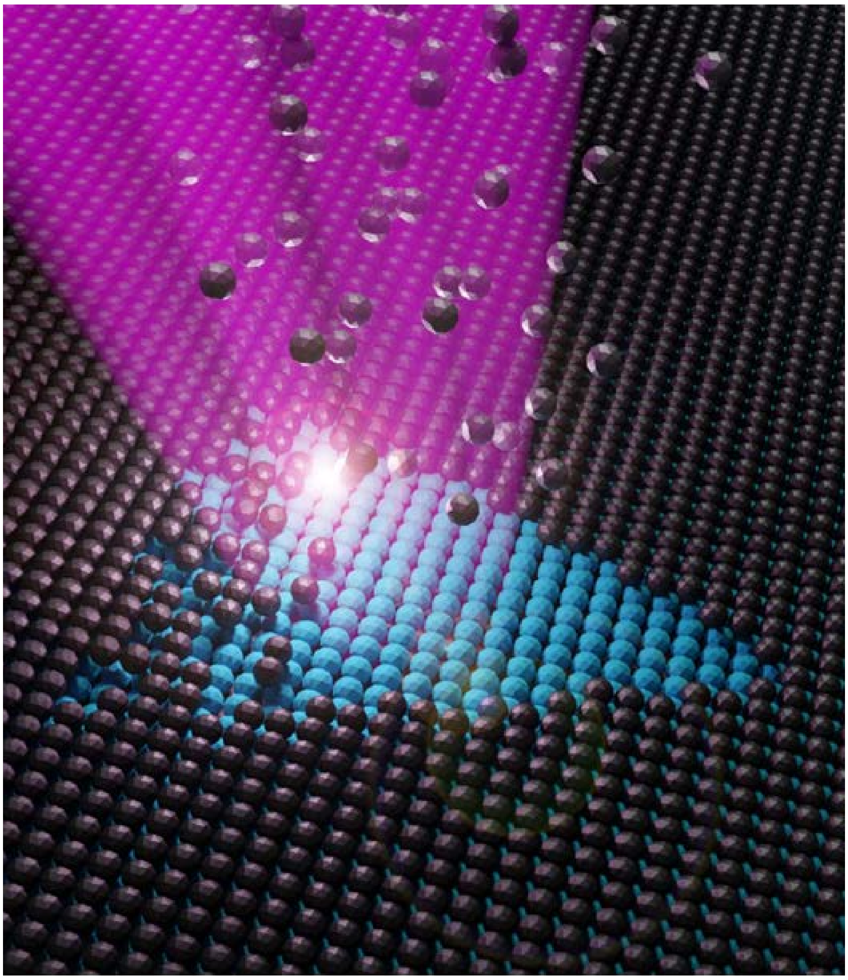


Credit: T. Wüstefeld/R. Röhlsberger, European XFEL/Helmholtz Institute Jena

Atomic clocks are currently the world's most accurate timekeepers, with numerous applications benefitting from their superior accuracy, such as precise positioning in satellite navigation. Studies at a FEL facility allowed to take a decisive step towards a new generation of ultraprecise nuclear clocks. Based on nuclear excitation of the element scandium (Sc), scientists triggered a transition in the nucleus of the metallic element and were able to measure its extremely narrow nuclear resonance. This outlines a pathway towards the most precise nuclear clock yet, accurate to about one second in 300 billion years, which is a thousand times more precise than current caesium-based atomic clocks.[40]

[39] https://journals.aps.org/prapplied/abstract/10.1103/PhysRevApplied.13.024064
[40] https://www.nature.com/articles/s41586-023-06491-w

Truly scalable quantum computers



Credit: P. Constantinou, Paul Scherrer Institute

In the rapidly advancing domain of semiconductor technologies and quantum computing, scientists have developed methods to engineer devices at the atomic scale. Yet, the challenge of patterning large-scale devices presents a significant obstacle to scale-up, particularly when it comes to fabricating extensive arrays required for dopant-based qubits in silicon. Now, experiments at a synchrotron source have made a breakthrough in achieving this using photons of light. They demonstrated the potential of a technique called extreme-ultraviolet light (EUV) lithography for the manufacture of silicon-based quantum nanoelectronics, the building block for truly scalable quantum computers.[41]

[41] https://www.nature.com/articles/s41467-024-44790-6

CULTURAL HERITAGE

What do Byzantine plaster figurines, Dürer paintings, ancient papyri, and Stradivari violins have in common? They can all be examined using X-ray light. This allows researchers to uncover their secrets without causing any damage - no samples are taken, and the objects aren't even touched.

A variety of advanced methods enable scientists to study paint degradation in famous artworks or reveal hidden layers beneath overpainted drawings. These techniques are commonly used by major museums, such as the Louvre in Paris and the Egyptian Museum in Berlin.

Byzantine plaster figurines from the Jordan Museum

Credit: Sahar al Khasawneh, SESAME

The elemental makeup of Byzantine plaster figurines from the Jordan Museum has been dissected, without having to do it physically. Its analysis at a synchrotron source reveals that the figurines' bodies are crafted from calcium carbonate, with specific inclusions. Remarkably, the enigmatic black drawings were decoded as charcoal, and an intricate mirror fragment was not of silicon origin but a polished amalgam of manganese, gallium, and lead. This research marks a significant leap in preserving cultural heritage, employing advanced synchrotron radiation technology to unveil the secrets of ancient craftsmanship.[42]

Following the traces of Albrecht Dürer

Credit: Staatliche Museen zu Berlin, Kupferstichkabinett / Dietmar Katz Public Domain Mark 1.

Metal point drawings belong to the most precious treasures of graphical art collections. This portrait of Willibald Pirckheimer (1503) by Albrecht Dürer (1471-1528) bears an additional inscription, of rather delicate content, written in Greek letters. Since Dürer himself did not know Greek, it has been argued that the inscription was added later and without Dürer's knowledge. Another suggested explanation is that the inscription was added by the sitter Pirckheimer himself shortly after the creation of the portrait. In cooperation with the National Museums in Berlin and the Louvre Museum, an investigation of the trace element composition of the silver marks (or strokes) performed at a synchrotron revealed that the same silverpoint was used for both the drawing and the inscription, therefore giving credit to the theory that Dürer was aware of the inscription.[43]

[42] http://maajournal.com/Issues/2023/Vol23-1/7_al%20Khasawneh_23(1).pdf
[43] https://www.sciencedirect.com/science/article/pii/S058485470400223X?via%3Dihub

Virtual unfolding of folded papyri

Credit: Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International

Ancient documents are of great historical importance, revealing information about the heritage of ancient cultures. Often, they are rolled or folded, their texts are hidden, and their sensitivity and fragility do not allow them to be unfolded. Virtual unfolding using synchrotron light grants non-destructive access to the hidden texts. Currently, a boxful of various folded papyri packages at the Louvre Museum in Paris are awaiting unfolding and unrolling.[44]

Unveiling Stradivari's secrets

Credit: C. Stani, Elettra Sincrotrone Trieste

Scientists studied at a synchrotron facility two Stradivari violins, the Toscano 1690 and the San Lorenzo 1718. The main goal was to answer a long-debated question: did Antonio Stradivari use a proteinaceous ground coat, spread directly on the wood surface before the varnish layers? A cutting-edge multi-instrumental analysis unequivocally confirmed the presence of these proteins within the preparation layer, in close proximity to the first row of wood cells, revealing new details on the manufacturing process of his invaluable instruments.[45]

[44] https://www.sciencedirect.com/science/article/pii/S1296207419301670?via%3Dihub
[45] https://pubs.acs.org/doi/10.1021/acs.analchem.2c02965

MORE RESEARCH

LEAPS facilities also play a role in advancing our understanding of the universe. Using powerful beams of X-ray and infrared light, researchers can study the composition and behaviour of cosmic materials, such as meteorites and interstellar dust, in unprecedented detail.

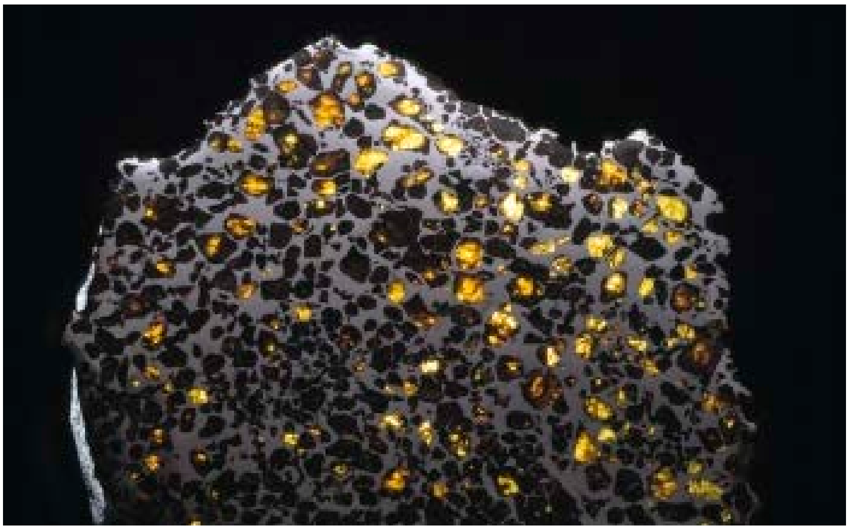
These Accelerator-based photon sources enable scientists to simulate extreme conditions found in space, helping to unravel mysteries about star formation, planetary evolution, and the fundamental properties of matter in the cosmos. This cutting-edge research provides valuable insights into the origins and dynamics of the universe.

Discovering the primordial universe

Credit: CC0 Public Domain

In January 2024, a team from the Italian National Institute of Astrophysics started the analysis of two precious samples of the Ryugu asteroid at a synchrotron as part of an international call for the analysis of cosmic materials brought back to Earth by the Hayabusa-2 mission of the Japanese Space Agency JAXA. The research group is focused on studying organic matter and water present in these samples in order to learn more from these real fossils of the solar system, which would date back to the very early stages of formation of our planetary system.[46]

Hard disc from space



Credit: © Natural History Museum, London

Meteorites have a long and violent history behind them. Geologists from the University of Cambridge reveal hidden magnetic messages in meteorites dating back to the early solar system with data acquired at a synchrotron. This information captures the dying moments of the magnetic field as the core of the meteorite's parent body solidified, providing a sneak preview of the fate of Earth's own magnetic field as its core continues to freeze.[47]

[46] https://dafne-light.lnf.infn.it/research/highlights/ryugu-asteroid/
[47] https://www.nature.com/articles/nature14114

LEAPS AND INDUSTRY – AN INNOVATION BOOSTER

Synchrotron radiation facilities, with their unique ability to examine materials at atomic and molecular levels, play a **pivotal role in advancing scientific research and fostering collaboration between academia and industry**. These sophisticated tools are handy for many industries, including pharmaceuticals, environmental studies, and materials science.

In **drug design**, synchrotron radiation enables scientists to swiftly identify protein structures. This not only aids in determining how drugs interact but also helps in understanding diseases, thereby accelerating the discovery and development of new medicines. In **materials science**, synchrotron light facilitates the precise evaluation of material structures, which drives progress in advanced materials, nanotechnology, and semiconductors. Environmentalists leverage these machines to investigate contaminants and soil components, while aerospace engineers study stress distributions within aircraft bodies made from different materials.

The **collaborative nature of synchrotron research**, where scientists and industry work together, is a key **driver of innovation**. It lowers entry barriers and helps to integrate synchrotron capacities into production processes seamlessly. The resulting inventions lead to new products and technologies, fostering innovation, competitiveness, and economic growth. The support provided to these alliances ensures that scientific findings meet immediate industrial needs, while also creating a platform for future technological discoveries.

TRAINING, OUTREACH AND EDUCATIONAL MATERIALS

Mobilising LEAPS' substantial collective knowledge, experience and expertise in synchrotron and FEL science and technology and in research infrastructure management will benefit European science and society. Each of the consortium members produces and makes resources available in many different formats. These are located on the members' individual websites and can take the shape of films and simulations, webinars, podcasts, even board games.

LEAPS facilities have school labs, a visitor programme, internships, summer schools, and specific outreach activities for university students and potential young researchers. Additionally, most facilities include in their yearly agenda a number of Open Days adjusted to the general public or specific target groups. LEAPS facilities are active in social media.

Individual facilities have up to 100 000 impressions and several tens of thousands of followers on their social media channels. At least one article in the press or a contribution in radio or television comes out each week. By participating in science fairs, the facilities make contact to 30 000 to 40 000 people - not counting visitors to street festivals where facilities present themselves to the general public. These are average numbers per year.

More information can be found in the Education, Training and Outreach of LEAPS.[48]

Credit: Escola Gaspar de Portolà, Balaguer (Spain)

Credit: Highlights der Physik in Regensburg (Germany), HZB

[48] https://www.leaps-initiative.eu/working-group/wg-6-education-training-outreach/

SCIENCE DIPLOMACY – SCIENCE FOR PEACE

Talent is spread across the globe equally, yet opportunities are not. Efforts are being made by large-scale research facilities to bridge this gap. Multidisciplinary, multi-user facilities like the LEAPS facilities embrace diversity, drawing scientists not only from across Europe, but from around the globe and from diverse research backgrounds. Scientists from across the breadth of Europe have benefited from the integrating activities of the recent decades which have helped support scientific users of all communities, growing the communities of those scientists in nations without light sources but whose access can be funded. Such support can be very effective in democratising access to distant users. Significantly, with researchers hailing from over 90 countries, LEAPS facilities serve as catalysts for exchanging ideas and forming enduring collaborations that transcend borders and disciplines.

18th SESAME User Meeting 4th and 5th May 2023.
Credit: © SESAME 2023

Taking a global look at the landscape of science and education reveals a significant imbalance of opportunities. Inequality, poverty, social exclusion, and lack of opportunity are deeply interconnected, with the lack of access to education from primary schools to universities being a significant contributor. However, research and education are not just essential pillars for sustainable development, gender equality, self-determination, and self-empowerment; they are also vital in creating equal opportunities for a peaceful future and addressing global challenges. Unfortunately, in the past, low- and medium-income countries have been left out of the knowledge-sharing loop, with most knowledge exchange and large-scale facilities concentrated in the northern hemisphere. To address this, LEAPS facilities have implemented outreach and inclusion activities, training programmes, schools, and internships. Moreover, efforts have been made to facilitate remote access to research at light sources.

The **LEAPS statement on Inclusion, Diversity, Equity, and Anti-discrimination (IDEA)**[49] clearly and unanimously expresses a vision of a world where European science is a catalyst for solving global challenges, a key driver for competitiveness, a compelling force for closer integration, and an initiative for peace through tighter scientific collaboration. As presented above, examples of light sources championing this cause include collaborative research to address global challenges as well as overcoming social and economic imbalances through research and higher education.

Now, more than ever, individual scientists, large-scale science facilities, science organisations, and scientific user organisations are becoming ambassadors for peaceful cooperation. Science has the responsibility to unite the world for the benefit of all humans, for peace and equal opportunities. As light sources, we wholeheartedly embrace this responsibility.

[49] https://www.leaps-initiative.eu/leaps-idea/#:~:text=LEAPS%20IDEA%20is%20the%20taskforce%20dedicated%20to%20Inclusion%2C,Best%20Practices%20in%20the%20various%20LEAPS%20member%20facilities

EPILOGUE

Two hundred years ago, lighting relied on candles, which were smelly, sooty, and hazardous. The grand challenge of that era was to create better candles. Back then, scientists exploring electricity were seen as engaging in eccentric and dangerous activities.

History teaches us that solutions to problems are not always found where we expect, and that basic research can lead to unforeseen revolutionary transformations. Sometimes, it takes years or even decades for a research project to culminate in a product, as seen in the development of microchips. Yet, at other times, results come suddenly, like those from the research done at accelerator-based photon sources in rapid response to the immediate threat of COVID-19.

Through both applied and curiosity-driven research, accelerator-based photon sources contribute to solving societal challenges, promoting sustainable development, and ensuring the long-term prosperity of our knowledge-based societies.

ACKNOWLEDGEMENTS

The LEAPS consortium is very grateful for the support provided by the National Funding Agencies as well as by the European Commission. Without their generous funding, the work of LEAPS and its participating facilities would not be possible. Collaborations with other nationally funded research institutions and universities further enrich the work of the consortium and ensure that the research done at LEAPS facilities and by LEAPS partners is societally relevant and impactful.

LEAPS also gratefully acknowledges the role of the scientific users of the facilities, whose capacity, diversity of interests, approaches and expertise, not to mention their scientific excellence, have helped drive the output and impact and have helped fulfil our mutual responsibilities in many societally relevant areas. LEAPS also acknowledges the facility user organisations, the national user organisations, and the European user organisation ESUO, who have all been partners in our activities within the facility at the national scale, upwards to the European scale, and beyond.

LEAPS facilities acknowledge the support provided to scientific users by the European Commission and the decades of support in the form of successive Framework Programmes for Integrating Activities, and thank the Commission on behalf of our user communities for enabling the transnational access to our facilities.

LEAPS League of European Accelerator-based Photon Sources

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