SOLARIS synchrotron

JAGIELLONIAN UNIVERSITY IN KRAKOW

SOLARIS NATIONAL SYNCHROTRON RADIATION CENTRE

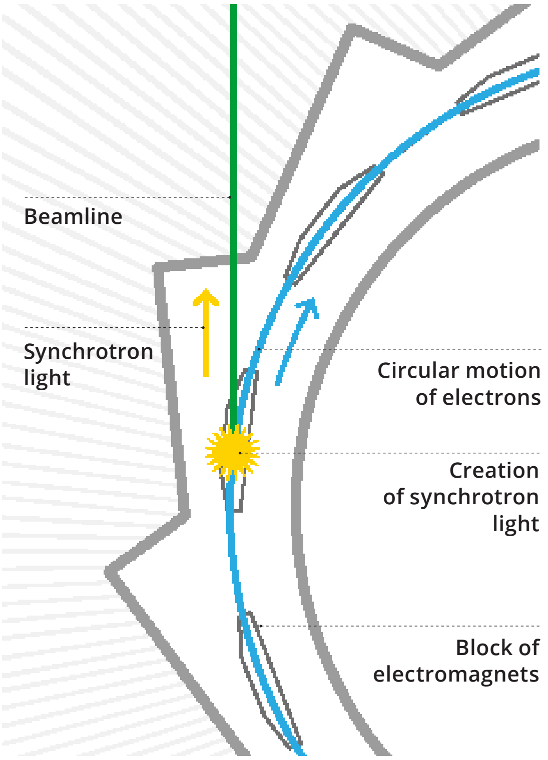
What is a synchrotron?

A synchrotron is a cyclic accelerator, i.e. a device in which particles are accelerated and travel around a fixed closed-loop path (in contrast to linear accelerators in which accelerated particles move in a straight line).

In the SOLARIS synchrotron, electrons circulate. They are produced in an electron gun and transferred to a linear accelerator, where they are accelerated to a speed close to the speed of light in a vacuum. Then these electrons are injected to the synchrotron, where they perform over three million laps in one second! In order for the electrons to rush around on a closed-loop path, their movement path is curved by twelve blocks of electromagnets. Electromagnetic radiation called synchrotron light is generated in the places where the path of the electrons is curved.

The synchrotron light is taken out of the synchrotron: first it goes to the so-called beamlines and then to end stations, where it is used for scientific research.

A synchrotron is a device that produces synchrotron light used for scientific research.



Synchrotron light is unique. Its extraordinary properties include its enormous intensity; it is millions of times brighter than the light that comes to the Earth from the Sun. In addition, synchrotron radiation contains electromagnetic waves all the way from the infrared spectrum, through visible and ultraviolet light, and up to X-rays. Thanks to this, scientists can study various materials in many ways, both externally and internally. In this way, they learn how these materials are built, and what their chemical composition and electrical or magnetic properties are.

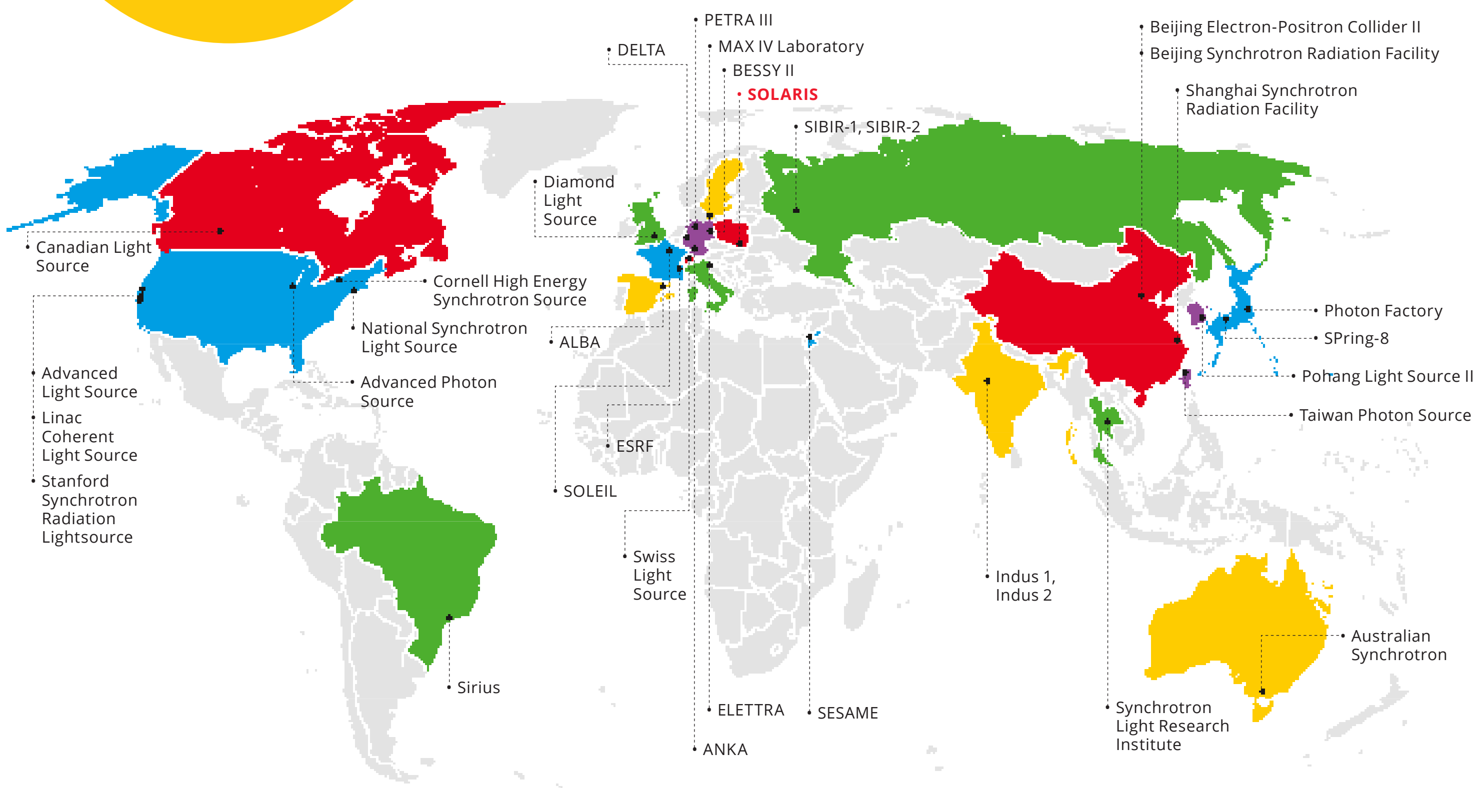
Many types of measurements are only possible when synchrotron light is used. This light also allows scientists to get better quality information in less time than by using traditional light sources.

Synchrotrons in the world

Synchrotrons work 24 hours a day, seven days a week, providing radiation for scientists conducting measurements simultaneously at many experimental end stations. They are real research factories. Because synchrotrons offer such vast opportunities, they are used in many branches of science such as biology, chemistry, physics, material engineering, nanotechnology, medicine, pharmacology, geology, and crystallography.

Synchrotrons are research factories in which samples of various materials, mainly solids, are analysed.

Currently, there are about 30 synchrotron centres in the world. Most of them are located in Europe, East Asia and the United States, i.e. in highly developed regions whose economic development is based on knowledge and innovation.



Why do we need synchrotron research?






Most synchrotron measurements are fundamental, and their purpose is to obtain new knowledge on the structure of materials and their inner processes. **This knowledge lays the foundation for discoveries and has practical application.**

For instance, fundamental research stands behind LED lights and modern TV and mobile phone screens. Knowledge acquired thanks to synchrotrons is invaluable in designing more efficient electronic devices, for instance processors which are faster and use less energy.

Materials used in solar panel production have been tested for years to increase their capability for turning solar power into electricity. Finding out more about the magnetic characteristics of materials can help to produce faster ways of storing even more data. Diffraction studies of protein structures and other biological molecules lead to increased knowledge of life process and help in the development of new drugs.

Moreover, synchrotrons enable research to be conducted on the chemical conversion of carbon dioxide to fuels, alcohols, hydrocarbons, polymers and plastics. These projects can help solve the problem of global warming.

A synchrotron is the accelerator of an innovative economy.

About the SOLARIS synchrotron

The SOLARIS synchrotron is the largest scientific research device in Poland. It is also the first and only synchrotron light source in Central Europe.

The Kraków synchrotron was built using the most modern technologies and following an innovative project designed by specialists from the Swedish MAX IV Laboratory. Thanks to this, the electron beam has excellent parameters despite the relatively small size of the device. **And this, in turn, puts the Kraków synchrotron at the forefront of this type of device in the world.** Ultimately, more than a dozen beamlines will be operational in the experimental hall with approximately twenty end stations.

The SOLARIS Centre is a unit of the Jagiellonian University, located on the Campus of the 600th Anniversary of the Jagiellonian University Revival. The SOLARIS building was built in 2011–2014. The investment was co-financed by the European Union with funds from the European Regional Development Fund, as part of the Innovative Economy Operational Programme for 2007–2013. The experimental hall of the SOLARIS Centre will be expanded in the coming years. The space created will be filled with four beamlines requiring a large distance of a sample from the synchrotron radiation source, as well as with two cryo-electron microscopes. A sample preparation laboratory will also be established.

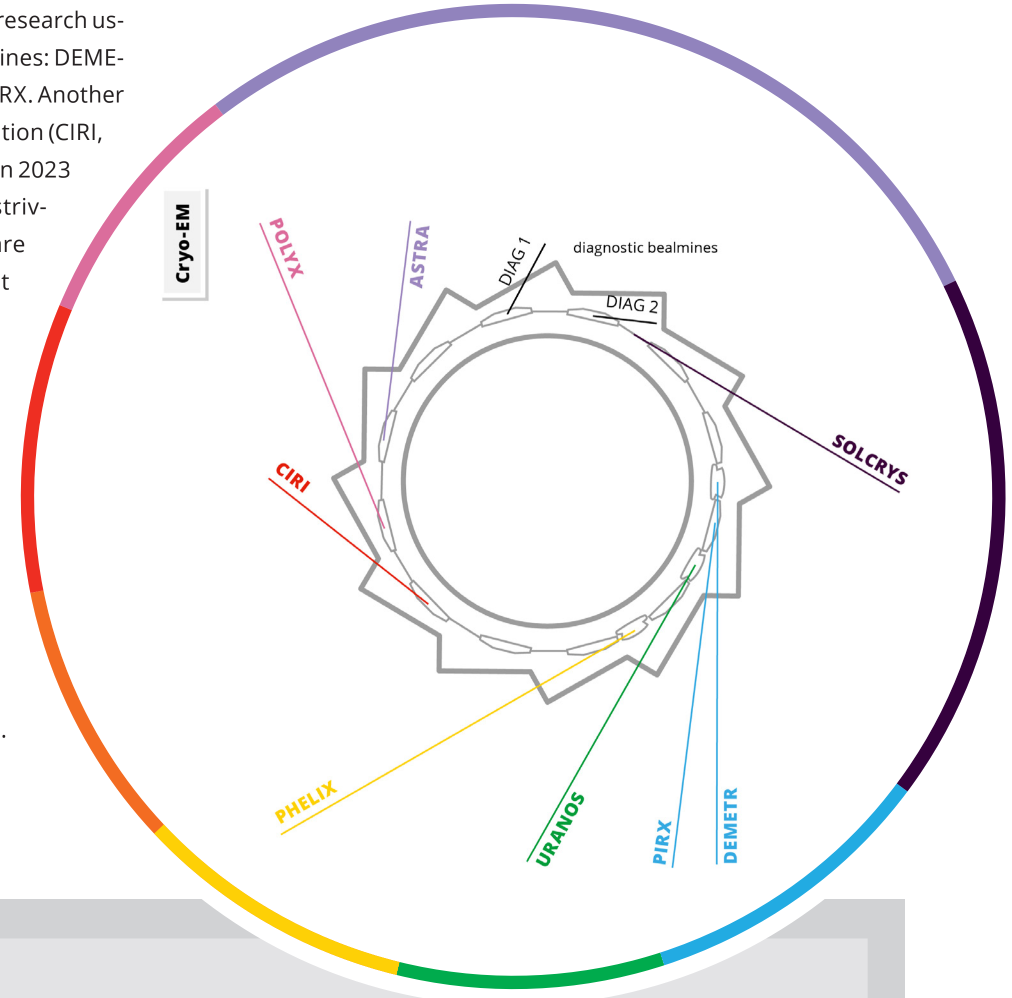
Currently, the SOLARIS Centre employs over 100 people. The core of the team is a highly qualified scientific and engineering staff, composed of graduates of the best Polish universities (such as the Jagiellonian University, the AGH University of Science and Technology, the University of Silesia and Adam Mickiewicz University). Many SOLARIS employees have received scholarships at leading universities and research centres in Europe and the United States. The functioning of SOLARIS is also supported by administrative and financial specialists, as well as specialists in the field of promotion and cooperation.

Selected SOLARIS synchrotron parameters

synchrotron circumference	96 m
electron energy	1.5 GeV
maximum electron current	500 mA
natural emittance (bare lattice)	6.5 nm rad
electron lifetime	13 h

Beamlines and Cryo-EM

Currently, scientists can conduct research using five SOLARIS synchrotron beamlines: DEMETER, PHELIX, ASTRA, URANOS and PIRX. Another three beamlines are under construction (CIRI, POLYX, SOLCRYS) and will be ready in 2023 and 2024. At the same time, we are striving to build new lines. Two more are in the concept phase. We hope that they will be launched in the coming years. In total, the SOLARIS beamlines will be fitted with about twenty end-stations.
SOLARIS Centre is more than the synchrotron alone. In our building, there are also two cryo-electron microscopes of the latest generation: Titan Krios G3i and Glacios. Both pieces of research equipment are parts of the National Electron Cryo-Microscopy Centre.



Cryo-EM - operational

The National Cryo-EM Centre uses two cryomicroscopes: Titan Krios G3i and Glacios. Thanks to them, it allows imaging of cells and their components, microorganisms (e.g. bacteria and fungi), and biomolecules (e.g. viruses, ribosomes, proteins, DNA, antibodies).

Research techniques: single particle analysis (SPA), electron tomography, microdiffraction (Glacios)
Titan Krios G3i cryo-electron microscope 300kV
Detectors: Gatan K3 BioQuantum, Falcon 3EC
Glacios cryo-electron microscope 200kV
Detectors: Falcon 4, CetaD

PIRX - *Premiere InstRument for Xas* - operational beamline

The beamline is designed to study chemical and electronic, structural and magnetic properties of samples exploiting X-ray absorption spectroscopy (XAS) and with polarized X-ray XNLD, XMCD, XMLD. The methods are suitable for probing element specific properties of bulk, surfaces, interfaces, thin films and nanomaterials. There are available three detection modes for X-ray absorption experiments: total electro yield (TEY), partial fluorescence yield (PEY) using SDD detector and intensity measured in transmission using AXUV photodiode.

Source: bending magnet
Beam size at sample (H x V): 250 µm x 40 µm
Photon energy range: 100–2000 eV
Radiation polarization: linear (horizontal) and elliptical
Research techniques: XAS, XMCD, XMLD, XNLD

PHELIX - *PH - photoelectrons; HELI - posibility of light polarizations change; X - energy which is within the X-ray range* - operational beamline

The beamline enables research on new materials, e.g. thin films, topological insulators, materials in the field of spintronics and magnetoelectronics, as well as biomaterials. The end station enables a wide range of spectroscopic and absorption studies characterized by different surface sensitivity.

Source: elliptically polarized undulator
Photon energy range: 50–1500 eV
Beam size at sample (H x V): 80 µm x 30 µm
Radiation polarization: variable linear, circular and elliptical
Research techniques: photoemission spectroscopy (ResPES, ARPES, SX-ARPES, SR-ARPES, XPS, UPS, CD-ARPES), XAS (TFY, TEY)

ASTRA - *Absorption Spectroscopy beamline in Tender energy Range* - operational beamline

The beamline is used for fundamental and applied research in materials science, physics, chemistry, biomedicine, and environmental protection. The available experimental techniques (XANES / EXAFS) in transmission (available in 2022), fluorescence (2023) and total electron yield mode (2023) allow to investigate the atomic environment of selected chemical elements in solid materials (both crystalline and amorphous) or samples in liquid or gas phase.

Source: bending magnet
Photon energy range: 1–15 keV (target)
Beam size at sample position (H × V): 10 × 1 mm
Radiation polarisation: linear
Research techniques: available in 2022 - X-ray absorption spectroscopy, XANES, EXAFS

POLYX - *POLYchromatic X-rays optics* - beamline under construction

The beamline will enable multimodal X-ray imaging and spectromicroscopy. Researches will be able to obtain spatial information on the internal structure, elemental composition and chemical compounds in investigated samples. The beamline will allow research in physics, chemistry, biological sciences, material, chemical, medical and environmental engineering, as well as in electronics, forensic medicine, archeology and protection of works of art.

Source: bending magnet
Photon energy range: 5–15 keV
Beam size at sample (H x V): 2 µm x 2 µm - 20 mm x 3 mm
Radiation polarisation: linear
Beam type: white, monochromatic
Research techniques: X-ray multimodal imaging and micro-focused X-ray absorption spectroscopy (µXRF, XRF-CT, µXAFS, µCT)

URANOS - *Ultra Resolved ANgular phOtoelectron Spectroscopy* - operational beamline

The beamline can be used to study new opto-, spin-, magneto-electronic materials, and nanostructures, as well as in superconductor and semiconductor, semimetals physics, topological matter. Angle-resolved photoemission spectroscopy (ARPES) measurements allow for a full experimental description of the electron structure of matter.

Source: unperiodical elliptically polarized undulator Apple II
Photon energy range: 8–150 eV
Beam size at sample (H x V): 200 µm x 200 µm
Radiation polarization: linear – vertical, horizontal, circular, elliptical, linear skewed
Measurements technics: ARPES, spin-ARPES (in near

DEMETER - *Dual Microscopy and ElecTron spEctRoscopy beamline* - operational beamline

Beamline is shared between two independent branches with dedicated experimental endstations: PEEM (photoemission electron microscopy) and STXM (Scanning Transmission X-ray Microscope). Scanning transmission X-ray microscope (STXM) allows chemical analysis at the nanoscale. PEEM is a perfect tool that combines spectroscopy and microscopy in one system to characterise the structural, chemical, electronic and magnetic properties of thin films, surfaces and interfaces. Due to energy range DEMETER is covering, beamline can be used in different fields such as nanotechnology, surface science, biomedicine, catalysis or environmental science.

Source: elliptically polarized undulator EPU
Photon energy range: 150–2000 eV
Beam size at sample (H x V): STXM – 30nm -300nm, PEEM – 36 µm x (5-200) µm
End stations: PEEM | STXM
Research techniques: STXM, XMCD, XMLD, XPEEM, µXAS, µXPS

CIRI - *Chemical InfraRed Imaging* - beamline under construction

The infrared beamline will allow to undertake research, development and application works in biomedicine, nanotechnology, archaeology, art conservation, and environmental science. The beamline will enable chemical imaging from macro- to nanoscales, providing information about the composition and molecular structure of the samples.

Source: bending magnet
Photon energy range: 12,5 meV – 500 meV
Beam size at sample (H x V): 10 µm x 50 µm
Spectral range: 4000 cm^{-1} – 100 cm^{-1}
Radiation polarisation: linear, circular
End stations: FTIR and AFM microscopes
Research techniques: IR microscopy and imaging (with an FPA detector), AFM-IR-sSNOM imaging

SOLCRYS - *SOLaris; CRYStallography* - beamline under construction

Research carried out on the beamline will be used in biological sciences, medicine (drug design), chemistry, and materials science. End stations will enable analyses of the structure of proteins, viruses, nucleic acids, and polymers. These studies provide knowledge on the molecular basis of living organisms, and on the architecture of macromolecules.

Source: wiggler
Photon energy range: 5–15 keV
The transverse size of the radiation beam: 50 um x 50 um
End stations: MX - macromolecular crystallography and SAXS - small angle X-ray scattering
Research techniques: structural studies of biomacromolecules in a crystal (MX), studies of the structure of non-crystalline systems (SAXS/bioSAXS).

How can I use the SOLARIS research infrastructure?

The SOLARIS synchrotron beamlines and the electron cryo-microscope can be used by any scientist (both from Poland and abroad) whose application for beam time is accepted by the international review panel. Even more importantly, access to SOLARIS is free of charge for anyone who carries out non-commercial research. In 2018–2021, researchers conducted 269 experiments at SOLARIS, including 58 at the URANOS beamline, 90 at the PIRX beamline, 9 at the PHELIX beamline, 32 at the PEEM end station and 2 at the STXM end station (both currently located on DEMETER beamline) and 78 on Cryo-EM. Accepted proposals were submitted by scientists from 94 universities and research institutes, including 39 Polish and 55 foreign ones. SOLARIS Centre users conducted research in physics, materials engineering, chemistry and biology.

The use of SOLARIS research infrastructure is completely free of charge.

Calls for proposals are organised twice a year, in spring and autumn. Experiments accepted in the spring call are carried out from September of the same year to February of the following year. Autumn experiments are conducted from March to August of the following year. Proposals should be submitted through the SOLARIS Digital User Office (DUO) website. The application must be written in English. You can submit any number of proposals in each call.

SOLARIS proposal structure

General information	→ proposal title → authors → identification of a beamline and an end station → specification of synchrotron parameters necessary for conducting the experiment
Scientific part	→ abstract → scientific background → experimental methods → identification of a beamline and beam time requested → results expected and their significance in the respective field of research → references
Samples	→ detailed description of samples to be analysed

How to submit a proposal?

1. **consult your research project with a beamline manager** →
2. **create an account at the SOLARIS Digital User Office website and register your affiliation** →
3. **fill in a beam time application form in DUO** →
4. **check your proposal carefully and send it**

Proposals are subject to:

- technical evaluation, which determines whether the experiment can be conducted on available research infrastructure,
- (sample) safety evaluation,
- substantive evaluation, focusing on the scientific value of the planned experiment.

The highest rated proposals are those with a high level of innovation in planned research, precise scientific hypotheses, clearly defined methodology and anticipated research results. Previous scientific achievements are also taken into account.

Beamline managers and employees of the SOLARIS User Office provide assistance in preparing proposals.

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We provide scientistists with:

- synchrotron radiation with unique properties and excellent parameters,
- substantive and technical support of beamline managers from preparation of the proposal to publication of the results,
- professional IT service during measurements,
- support in organising arrival in Kraków and stay in the city during measurements,
- after measurements, the opportunity to visit monuments listed on the UNESCO World Heritage List.

SOLARIS Digital User Office
https://duo.synchrotron.pl

CERIC-ERIC: even more research possibilities

In 2016, Poland became a member of the Central European Research Infrastructure Consortium. CERIC-ERIC brings together specialised laboratories from the leading research centres of Central Europe and Italy. At these facilities, research is conducted using photons, electrons, neutrons, and ions. The Polish partner facility is the SOLARIS synchrotron.

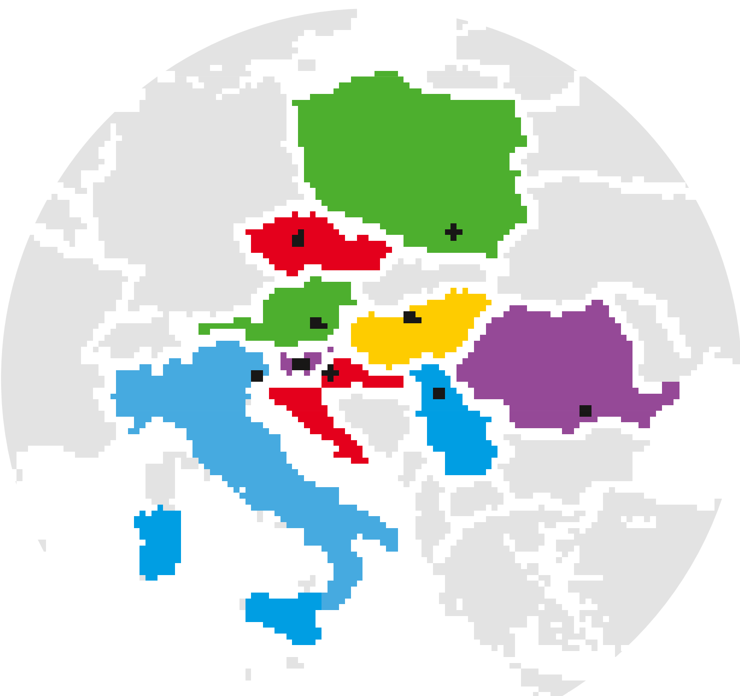
Thanks to CERIC-ERIC, Polish (and foreign) scientists can apply for access to 50 end stations and laboratories free of charge. The consortium's offer is directed to scientists in such fields as chemistry, physics, electronics, nanotechnology, materials engineering, biology, medicine, pharmacology, biotechnology, geology and environmental protection.

In addition to providing free access to the CERIC-ERIC research infrastructure, the consortium covers the travel and accommodation costs of the scientists who conduct the experiments. It also finances the publication of selected research results. CERIC-ERIC partner facilities provide substantive and technical support during measurements. Some allow for feasibility studies.

CERIC-ERIC calls for proposals are organised twice a year, in March and in September. Proposals may be pre-evaluated and sent back to the scientists, so that he or she can improve them. This significantly increases the chance of the proposal being accepted.

In some cases research projects must include measurements using at least two complementary research techniques.

www.ceric-eric.eu



ITALY | TRIEST
Elettra synchrotron

POLAND | KRAKÓW
SOLARIS synchrotron and Cryo-EM

HUNGARY | BUDAPEST
Budapest Neutron Centre

CROATIA | ZAGREB
Ion Beam Accelerators – Ruđer Bošković Institute

AUSTRIA | GRAZ
Graz University of Technology - Institute of Inorganic Chemistry

CZECH REPUBLIC | PRAGUE
Surface Physics Group, Charles University

ROMANIA | BUCHAREST
Laboratory of Atomic Structures and Defects in Advanced Materials, National Institute of Material Physics

SERBIA | BELGRADE
Vinča Nuclear Institute

SLOVENIA | LJUBLJANA
Slovenian NMR Centre, National Institute of Chemistry

SOLARIS for industry

SOLARIS Centre is open to industrial users. Our scientists are experienced in solving specific technological challenges of companies operating in various industry sectors and conducting advanced R&D projects. We offer a wide range of access modes, from primary access to our research infrastructure, to the comprehensive service encompassing all steps of the industrial research project. Research techniques available at the Centre can be used in chemical, materials, energy, oil and gas, electronics, biotechnology industries, as well as in environmental protection and engineering.

We invite you to contact our Industry Liaison Office. After receiving basic information about your business and technological needs, our industrial scientists will analyze the problem and create a roadmap of solving it using synchrotron radiation – based techniques.

Selected methods available for industry

XAS - X-ray absorption spectroscopy

- characterization of elemental composition and local spatial structure of materials,
- chemical sensitivity, including sensitivity to oxidation levels,
- possibility of in-situ/operando studies.

Contact for industry
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STXM - scanning transmission X-ray microscopy

- imaging with the spatial resolution down to 30 nm,
- chemical sensitivity - elemental mapping,
- possibility of in-situ/operando studies.

PEEM - photoelectron microscopy

- imaging with the spatial resolution down to 50nm,
- characterization of chemical and magnetic properties of materials,
- surface sensitivity.

PS - photoelectron spectroscopy in different modes

- surface sensitivity,
- characterization of chemical properties and elemental composition,
- determination of electronic and spin structure of materials.

Cryo-EM - cryogenic electron microscopy

- reconstruction of the structure of biomolecules without crystallization,
- cryo-electron tomography (cryoET),
- microcrystal diffraction (microED).

Visiting SOLARIS Centre

NSRC SOLARIS is the only facility in Poland that enables research with the use of synchrotron radiation. It is also the largest research center in the country, thus being an important point on the route of numerous excursions. Over the past four years, the center has been visited by nearly ten thousand people, including over two thousand primary and secondary school students.

Organized groups of young people and adults can visit NSRC SOLARIS throughout the year, but prior appointment is necessary. Due to the very high interest the reservation should be made at least one month in advance. The schedule of visiting groups is arranged in such a way to not interfere with the research activities of the Centre.

The tour begins with screening of a film about the synchrotron operation. Then, the visitors of the Centre are invited for a walk around the experimental hall, where they can see the synchrotron beamlines and cryomicroscopes with their own eyes. The groups are always accompanied by a guide, who is a SOLARIS scientist or engineering-technical employee. The visit to the Centre takes about an hour and a half, and is free of charge. The guided tours take place from Monday to Friday, from 9:00 am to 2:00 pm. Organized groups may have a maximum of 30 people.

The SOLARIS Centre also welcomes individual guests during the annual open days, as well as regular Krakow's city events (e.g. Scientists' Nights). The participants can not only visit the SOLARIS synchrotron experimental hall but also take part in numerous attractions prepared by the SOLARIS team on this occasion. In previous years, there were organized workshops for children, science and technology family competitions, and film screenings.

Organised group reservations
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