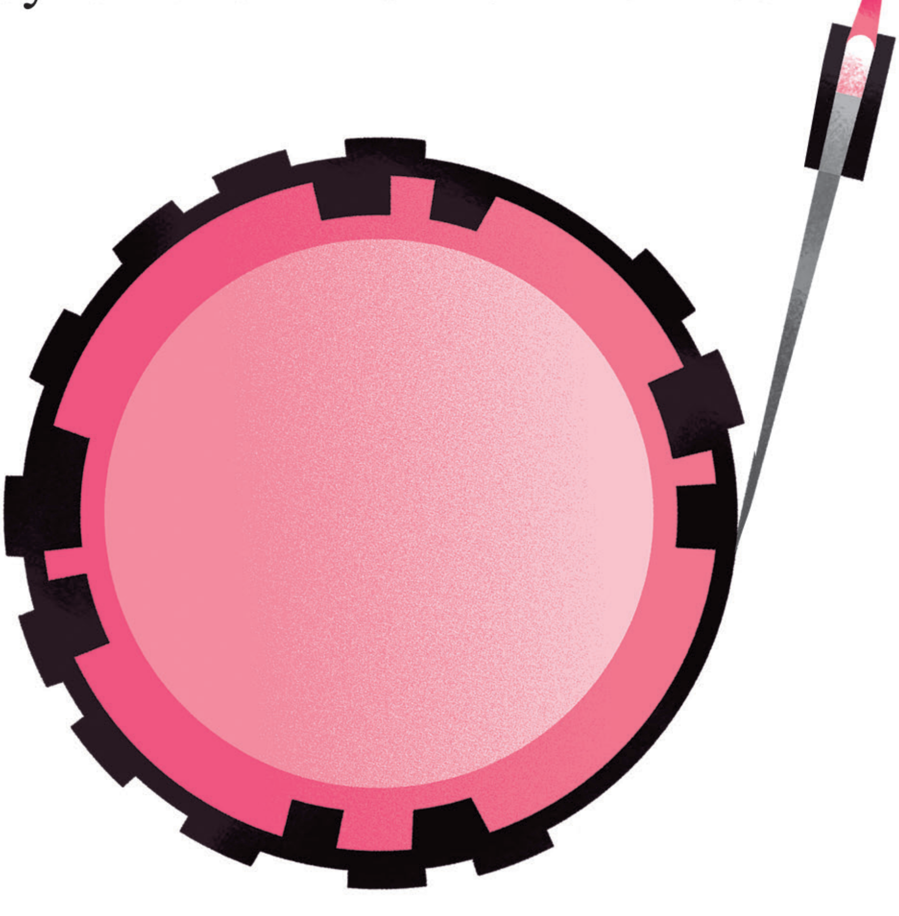
ENCYCLOPEDIA of the Synchrotron Radiation Facilities



ENCYCLOPEDIA OF THE SYNCHROTORON RADIATION FACILITIES
- SECOND EDITION -

In the three years since the encyclopedia was first published, synchrotron radiation research around the world has continued to progress. High-brightness light sources based on the MBA lattice are being built and remodeled, starting with MAX- IV in Sweden.

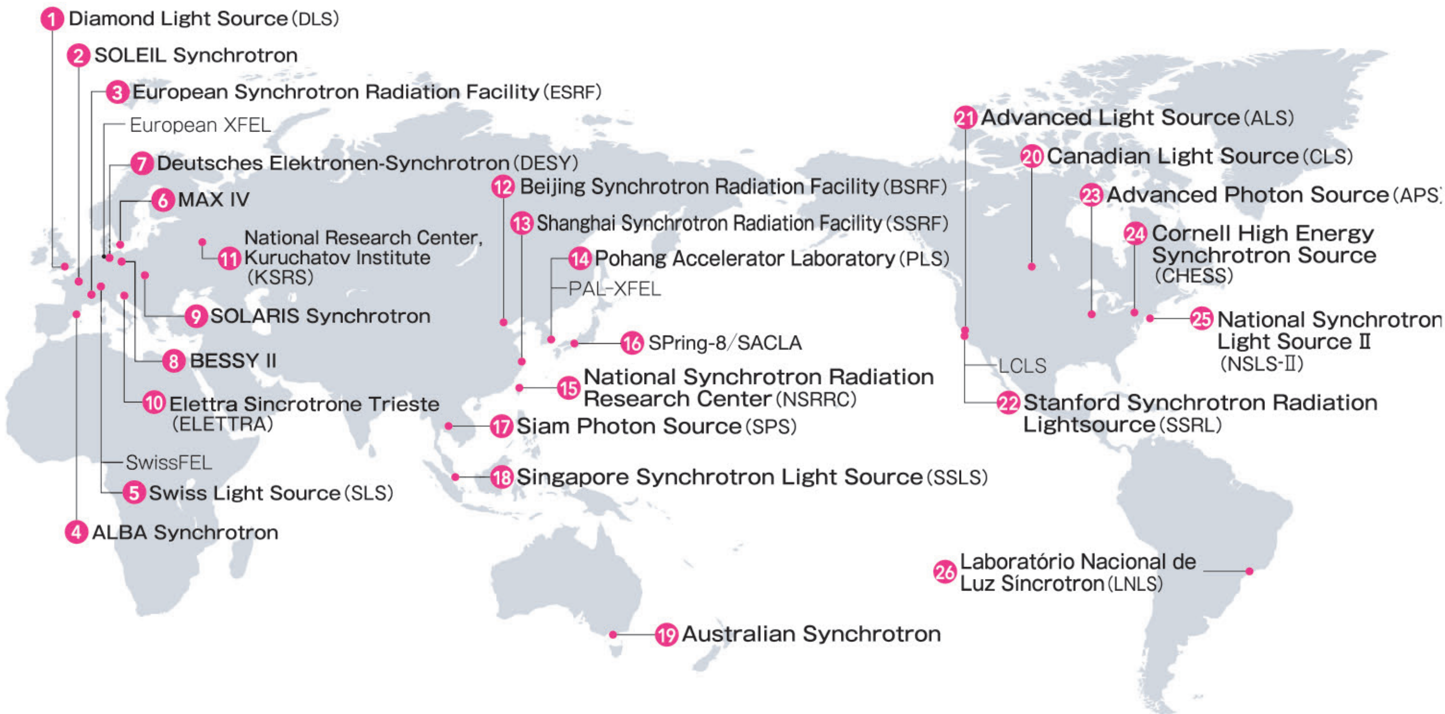
The field of synchrotron radiation has also greatly expanded, contributing to our understanding of phenomena based on structures and functions at the atomic and molecular levels in a wide range of fields, from basic science to applied science. Indeed, while we understand *how* many phenomena around us happen, we often don't know *why* they happen. Synchrotron radiation is the light that enables us to reveal many of these *whys*.

The United Nations has set seventeen Sustainable Development Goals. Synchrotron radiation is an essential tool for meeting these targets, and cooperation between synchrotron radiation facilities around the world will foster and accelerate progress.

We hope that this second edition will help to promote the necessary cooperation and contribute to deepening the mutual understanding among facilities.

Tetsuya Ishikawa
Director
RIKEN SPring-8 Center

Synchrotron Facilities in the world



1

Didcot, England

P.6～

Diamond Light Source(DLS)

England's only synchrotron facility, located near Oxford, is funded by the UK government and the Wellcome Trust. It supports research investigating a wide variety of materials from vaccines to turbine blades and catalysis, with particular strengths in structural biology and industrial engagement.

【Operation start】2007
【Circumference】562m
【Energy】3GeV
【Beamlines】33

2

Saint-Aubin, France

P.10～

SOLEIL Synchrotron

SOLEIL is a 3rd generation synchrotron radiation facility optimized to deliver brilliant beams over a large spectral range from infrared to hard X-ray. Its beamlines allow complementary experiments to explore the structure of matter and its electronic and magnetic properties combining scattering, spectroscopy and imagings.

【Operation start】2006
【Circumference】354m
【Energy】2.75GeV
【Beamlines】29

Many synchrotron radiation facilities are in operation around the world. Most of them are so-called third-generation sources. Here, we list the hard X-ray facilities. ESRF was the initial third generation facility in the hard X-ray region, followed by APS and SPring-8, which required electron energy greater than 6eV. Recently, the development of short-period undulators has made it possible to produce hard X-rays at around 3 GeV. Therefore, the new facilities are mid-sized, except for PETRA III in Germany, which restructured their collider ring for high-energy physics.

The performance statistics for the 3GeV facilities are well parametrized by their respective electron beam emittances. In 2014, NSLS-II in the US exceeded the high-energy storage rings, and MAX-IV in Sweden went far beyond by using an MBA lattice. These technologies have triggered an upgrade of high-energy storage rings and mid-sized facilities of 3 GeV. The ESRF upgrade accomplished an emittance at 0.2 nm, less than one-tenth the prior level.

3

Grenoble, France P.14~

European Synchrotron Radiation Facility(ESRF)

Supported by 22 partner countries, the ESRF is a centre of excellence for fundamental and innovation-driven research in condensed and living matter science. In August 2020, the ESRF will open a new generation of high-energy synchrotrons, the Extremely Brilliant X-ray Source (EBS), providing a 100-times more brilliant and coherent X-ray beam. It will provide the international X-ray science community with new tools to push the limits of knowledge in fields such as health, energy, environment, new sustainable and innovative materials, and also cultural heritage and palaeontology.

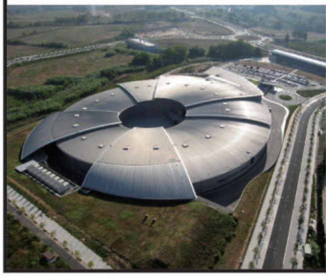
ESRF/J Chavy

【Operation start】 1994
【Circumference】 844m
【Energy】 6GeV
【Beamlines】 44

4

Sardañola del Vallés, Spain P.18~

ALBA Synchrotron Light Source



A new synchrotron facility near Barcelona. Industrial uses include research and development for pharma, cosmetics, agri-food and packaging.

【Operation start】 2012
【Circumference】 269m
【Energy】 3GeV
【Beamlines】8 operating, 4 in construction

5

Villigen, Switzerland P.22~

Swiss Light Source(SLS)

Science and technology research institute near Zurich. The third-generation synchrotron facility, Swiss Light Source, has two special beamlines for pharmaceutical use. Swiss FEL is now also available.

Paul Scherrer Institute

【Operation start】 2001
【Circumference】 288m
【Energy】 2.4GeV
【Beamlines】 17

6

Lund, Sweden P.26~

MAX IV Laboratory

Roger Eriksson

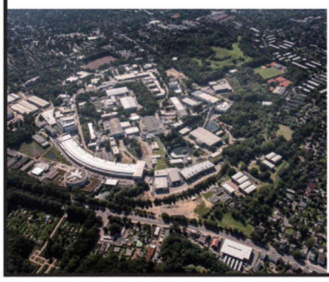
The Swedish national synchrotron, located in southern Sweden. Hosted by Lund University. Started as MAX I in 1986, with upgrades 1997 (MAX II) and 2007 (MAX III).

【Operation start】 2016
【Circumference】 96m / 528m
【Energy】 1.5GeV / 3GeV
【Beamlines】 16

7

Hamburg, Germany P.30~

Deutsches Elektronen-Synchrotron (DESY)



National research centre in Germany, operating and utilising the high brilliant X-ray source, PETRA III, and the soft X-ray free-electron laser, FLASH. DESY develops unique tools for more than 3000 users from over 40 countries every year. DESY is responsible for the superconducting accelerator for the European XFEL.

【Operation start】 PETRA III 2010 / FLASH 2005
【Circumference】 2.3 km / 260 m
【Energy】 6GeV / 1.25 GeV
【Beamlines】 22 (25 planned) / 7

8

Berlin, Germany P.34~

Berlin Electron Storage Ring for Synchrotron Radiation II (BESSY II)

BESSY II at Helmholtz-Zentrum Berlin (HZB) is a third-generation storage ring dedicated to the soft X-ray photon energy range, serving a multi-disciplinary international user community. BESSY II is the European radiation standard and is used for metrology purposes.

HZB/Volker Mai

【Operation start】 1998
【Circumference】 240m
【Energy】 1.72GeV
【Beamlines】 47

9

Krakow, Poland P.36~

SOLARIS Synchrotron

The first Polish synchrotron facility is located in Krakow in southern Poland. It was built at Jagiellonian University, one of the oldest universities in the world. SOLARIS serves as a national center for scientific research, supporting also researchers from other countries.

【Operation start】 2016
【Circumference】 96m
【Energy】 1.5GeV
【Beamlines】 14 (planned)

10

Trieste, Italy P.40~

Elettra Sincrotrone Trieste (ELETTRA)

A mid-sized synchrotron facility in northeast Italy near the Slovenian border. Users from 50 countries investigate many kinds of materials, including food. A free electron laser, FERMI, is also available.

【Operation start】 1994
【Circumference】 260m
【Energy】 2.0-2.4GeV
【Beamlines】 28

11

Moscow, Russia

P.44〜

Kuruchatov Synchrotron Radiation Source(KSRS)

Kuruchatov Institute was founded in 1943 to produce nuclear weapon. The building was almost finished in 1989, but economic difficulties delays the completion in 1999. The facility is used for physics, chemistry, biology and palaeontology.

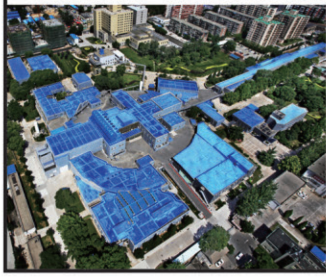
【Operation start】 1999
【Circumference】 124m
【Energy】 2.5GeV
【Beamlines】 19 (24 planned)

12

Beijing, China

P.46〜

Beijing Synchrotron Radiation Facility (BSRF)



Belongs to Institute of High-Energy Physics, Chinese Academy of Sciences. Offers electromagnetic beam ranging from vacuum ultraviolet to hard X-rays, and contributes to many scientific areas as well as physics.

【Operation start】 1991
【Circumference】 241.53m
【Energy】 2.5GeV
【Beamlines】 14

13

Shanghai, China

P.50〜

Shanghai Synchrotron Radiation Facility (SSRF)

SSRF is operated by the Shanghai Advanced Research Institute. It was built at Zhangjian Hi-Tech Park, only 30 minutes from Airport. A soft-X-ray free electron laser facility, SXFEL, and a hard-X-ray free electron laser facility, SHINE, are under construction at or close to the SSRF campus.

【Operation start】 2009
【Circumference】 432m
【Energy】 3.5GeV
【Beamlines】15 in operation
+ 16 under construction

14

Pohang, Korea

P.54〜

Pohang Accelerator Laboratory (PLS)

Operated by POSTECH at southeastern part of Korea. The Synchrotron, Pohang Light Source (PLS), operated in 1995 was upgraded to PLS-II in 2011. X-ray free electron laser facility PAL-XFEL is now available.

【Operation start】 2012(PLS-Ⅱ)
【Circumference】 282m
【Energy】 3GeV
【Beamlines】 35

15

Hsinchu, Taiwan

P.58〜

National Synchrotron Radiation Research Center (NSRRC)

The NSRRC is located at northwestern part of Taiwan. Combination of low energy and medium energy synchrotron facilities, TLS and TPS, offers the wide range and high brightness of photon beam.

【Operation start】 1994 (TLS)/2016 (TPS)
【Circumference】 120m/518m
【Energy】 1.5GeV/3GeV
【Beamlines】 25/10 (25 planned)

16

Hyogo, Japan

P.62〜

SPring-8

The largest synchrotron radiation facility at Koto, 40km away from Himeji. Wide research areas of particle physics, forensic, structural biology, etc. Industrial users, more than 20%, have invented new products.

【Operation start】 1997
【Circumference】 1,436m
【Energy】 8GeV
【Beamlines】 62

17

Nakhon Ratchasima, Thailand

P.66〜

Siam Photon Source (SPS)

The first state-owned synchrotron light source in Thailand, build at Suranaree University of Technology, 250km away from Bangkok. Typical investigations include local topics of interest such as cultural heritage, plant disease, pearls' colors and luminescence, and food applications.

【Operation start】 1996
【Circumference】 81.3m
【Energy】 1.2GeV
【Beamlines】 10

18

Singapore

P.70〜

Singapore Synchrotron Light Source (SSLS)

The compact light source, Helios II, based on superconducting magnets. at National university of Singapore. Clean room is attached inside the beamline. Offers education program for graduate students.

【Operation start】 2000
【Circumference】 10.8m
【Energy】 0.7GeV
【Beamlines】 8

19 Clayton, Australia

P.72～

Australian Synchrotron

Australian's only synchrotron facility, located near Melbourne. As a center for scientific activities in Oceania, it contributes to a variety of research ranging from basic science to industrial applications.

【Operation start】2007
【Circumference】216m
【Energy】3GeV
【Beamlines】10

20 Saskatoon, Canada

P.76～

Canadian Light Source (CLS)

Canada's national synchrotron, the CLS is a national research facility and one of the largest science projects in the country's history, used by more than 1,000 scientists from around the world every year in ground-breaking health, environment, materials and agricultural research.

【Operation start】2004
【Circumference】171m
【Energy】2.9GeV
【Beamlines】22

21 Berkeley, California, USA

P.78～

Advanced Light Source (ALS)

Photo courtesy of Lawrence Berkeley National Laboratory

A U.S. Department of Energy funded synchrotron facility at Lawrence Berkley National Laboratory that provides users from around the world access to the brightest beams of soft X-rays, together with hard X-rays and infrared, offering chemical, electronic, and structural insight to a wide range of disciplines.

【Operation start】1993
【Circumference】197m
【Energy】1.9GeV
【Beamlines】40

22 Menlo Park, California, USA

P.82～

Stanford Synchrotron Radiation Lightsource (SSRL)

The synchrotron radiation facility is a division of SLAC National Accelerator Laboratory. It was originally used as an electron-positoron collider, SPEAR, which contributed to the discovery of new particles. The original SPEAR accelerator was replaced with SPEAR3 in 2003.

【Operation start】1972
【Circumference】234m
【Energy】3GeV
【Beamlines】33

23 Lemont, Illinois, USA

P.86～

Advanced Photon Source (APS)

A U. S. Department of Energy facility located at Argonne National Laboratory near Chicago. The APS is a third-generation source optimized for producing hard X-rays. Research performed at APS has been the foundation of two Noble prizes.

【Operation start】1996
【Circumference】1104m
【Energy】7GeV
【Beamlines】68

24 Ithaca, New York, USA

P.90～

Cornell High Energy Synchrotron Source (CHESS)

Cornell High Energy Synchrotron Source (CHESS) is a high-intensity X-ray source which provides users state-of-the-art synchrotron radiation facilities for research in physics, chemistry, biology, environmental sciences and materials science.

【Operation start】1980
【Circumference】768m
【Energy】6GeV
【Beamlines】7

25 Upton, New York, USA

P.94～

National Synchrotron Light Source II (NSLS-II)

NSLS-II is a new, mid-sized synchrotron facility at Brookhaven National Laboratory in New York. It was build next to the original facility, NSLS, and produces X-rays that are 10,000 times brighter.

【Operation start】2015
【Circumference】792m
【Energy】3GeV
【Beamlines】
28 (60 planned)

26 Campinas, Brazil

P.98～

Laboratório Nacional de Luz Síncrotron (LNLS)

A second-generation facility opened in 1997. It was the first synchrotron light source in the southern hemisphere and it is currently the only one in Latin America. A fourth-generation synchrotron light source, Sirius, is being built. Commissioning is planned for mid-2018 and operation for users is set to start in 2020.

【Operation start】1997 (UVX)/ 2020 (Sirius)
【Circumference】93m/ 518.4m
【Energy】1.37GeV/ 3GeV
【Beamlines】20/ 40

XFEL Facilities

1

Hamburg, Germany

P.100~

European XFEL

International X-ray free electron laser facility operated through collaboration by 12 European countries. The superconducting accelerator enables a high repetition rate of up to 27,000 x-ray pulses per second for photon energies from 0.28 to beyond 20 keV.

【Operation start】 2017
【Length】 3.4km
【Energy】 17.5GeV
【Beamlines】 3

2

Villigen, Switzerland

SwissFEL

Compact X-ray free electron laser realized by in-vacuum undulators. Belongs to Paul Scherrer Institute. New infrastructure to move forward scientific activities in Switzerland.

【Operation start】 2017
【Length】 713m
【Energy】 5.8GeV
【Beamlines】 2

Paul Scherrer Institute

3

Pohang, Korea

Pohang Accelerator Laboratory-XFEL (PAL-XFEL)

Belongs to Pohang Accelerator Laboratory in southeast part of Korea. After first lasing in 2016, user service started in June 2017 as the second X-ray free electron laser facility in Asia.

【Operation start】 2017
【Length】 1.1km
【Energy】 10GeV
【Beamlines】 3

4

Hyogo, Japan

SACLA

SPring-8 Angstrom Compact Free Electron Laser

Compact X-ray free electron laser facility attached the synchrotron facility, SPring-8. Ultrashort pulses of femto-second order reveal ultrafast phenomena and enable measurement before destroy.

【Operation start】 2012
【Length】 700m
【Energy】 8GeV
【Beamlines】 5

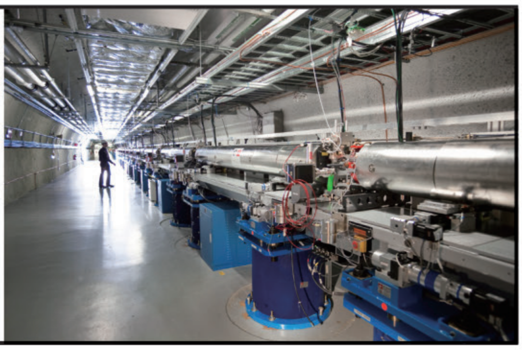
5

Menlo Park, California, USA

Linac Coherent Light Source (LCLS)

First X-ray free electron laser facility in the world. Belongs to SLAC National Accelerator Laboratory in California. Planning to upgrade into LCLS-II by introducing superconducting accelerators that enable high reputation rate. The LCLS-II upgrade is adding a second X-ray laser beam that's 10,000 times brighter, on average, and increases the laser's firing rate to up to 1 million pulses per second.

【Operation start】 2009
【Length】 4km
【Energy】 15GeV
【Beamlines】 1



Diamond Light Source

General Information

Diamond works like a giant microscope, harnessing the power of electrons to produce bright light that scientists can use to study anything from fossils to jet engines and from to viruses and vaccines.

The machine speeds up electrons to near light speeds so that they give off a light 10 billion times brighter than the sun. These bright beams are then directed off into laboratories known as 'beamlines'. Here, scientists use the light to study a vast range of subject matter. Whether it's fragments of ancient paintings or unknown virus structures, at the synchrotron, scientists can study their samples in atomic detail.

Diamond is a not-for-profit limited company funded as a joint venture by the UK Government through the Science & Technology Facilities Council (STFC) in partnership with the Wellcome Trust. The synchrotron is free at the point of access for proposals being submitted through a competitive peer review process, provided that the results are published in the public domain. Thousands of researchers from both academia and industry use Diamond to conduct experiments, assisted by approximately 750 staff.

The scope for industrial research and development at Diamond is greater than ever before, and the number of organisations using Diamond through the paid proprietary access mode now exceeds 170, ranging in size from small start-ups to global corporations. While the pharmaceutical sector is still the predominant user of Diamond beamlines, an increase in both usage and income is being seen throughout the physical sciences. Today, companies such as GSK, AstraZeneca, Sosei Heptares, Rolls-Royce and Infineum are supported by Diamond's dedicated Industrial liaison group.

Diamond is one of the most advanced scientific facilities in the world, and its pioneering capabilities are helping to keep the UK at the forefront of scientific research.

<u>Facts and Figures for Financial Year 2018/19</u>

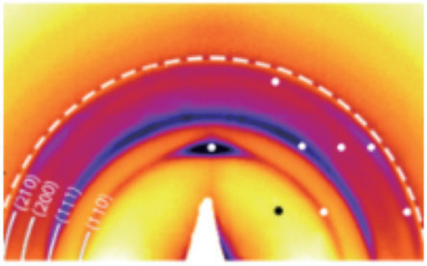
- When operations began: 2007
- Energy: 3 GeV, 300mA
- Number of proposals submitted for Peer Reviewed access: 1,788
- Shifts requested via Peer Review: 22,227 8-hour shifts
- Number of publications: 10,296 over the facility lifetime
- Usage type for academia and industry:
  - 8,253 physical on site user visits,
  - 5,313 remote user visits
- Success in maintaining beam: 98.4%

Diamond Light Source

Societal Impact

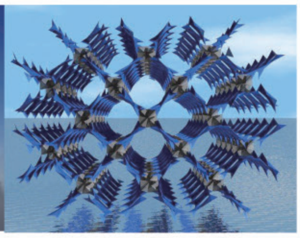
Energy: Solar wallpaper

Earth is exposed to enough sunlight in a couple of hours to power the entire world for a year; that's why it's so important to harness the sun's power. At Diamond, scientists are developing technology to create solar panels that are so flexible and cheap that they could be installed just like wallpaper on the outside of buildings.



Living with environmental change: Trapping noxious gas

Greenhouse gasses are damaging to the environment, but research at Diamond is helping to develop new materials which can capture and remove them from the atmosphere. Scientists at Diamond scrutinise the properties of naturally occurring materials and use them to develop advanced new materials. If fitted to energy stations, carbon capture materials could help reduce our carbon emissions, giving us cleaner, purer air.

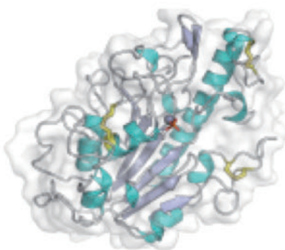
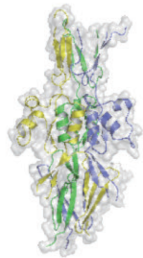



Global uncertainty: Radioactive waste storage

Nuclear waste storage is one of the most pressing issues faced by governments around the world. Teams working at Diamond are studying the impact of radiation damage in different minerals to help engineer holding facilities capable of safely storing waste for 1 million years.

Lifelong health & wellbeing: Fighting antibiotic resistance

Diamond is helping to combat the rise of antibiotic resistant bugs by allowing scientists to uncover the mechanisms by which bacteria defend themselves against drugs. A group of scientists have used Diamond to determine how certain bacteria construct their outer layer of defence, providing a target for new classes of antibiotics that would sidestep current resistance mechanisms.

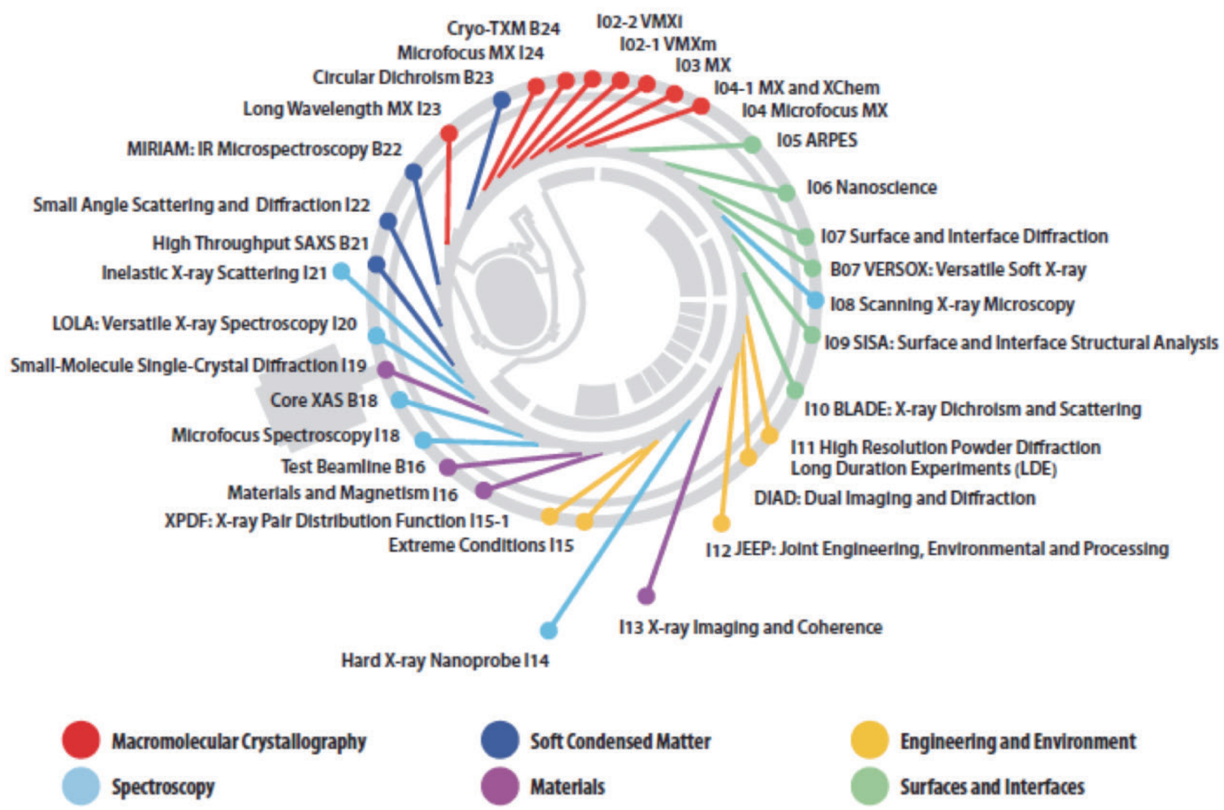
Global food security: Addressing global hunger

Wheat is one of the world's most popular foods; however, the human body isn't able to effectively absorb all of the rich nutrients inside wheat. By reducing the amount of a compound called 'phytate' in the grains, scientists at Diamond are helping to develop wheat that is far more nutritious. One billion people are permanently hungry and millions die each year as a consequence of deficiencies of iron and zinc; but these small changes to grains could help alleviate malnutrition worldwide.


Digital economy: Energy-efficient tech

Data storage technology generally uses magnetism to read and write binary code which is translated into sound and vision on a computer. However, the magnets need a good deal of power to function effectively. Scientists at Diamond are studying the properties of magnetic materials in order to develop more efficient technology that doesn't consume as much power. In this way, synchrotron light is helping to develop the next generation of energy-efficient gadgets.

Diamond Light Source



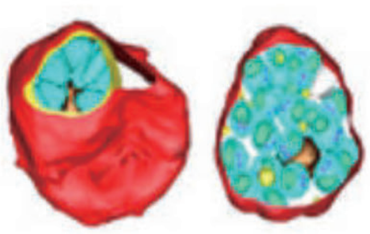
Electron Microscopes

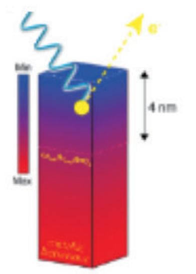
Microscope	Main Capabilities	Accelerating Voltages	Operational Status
Titan Krios I	Cryo-EM, cryo-ET	80, 120, 200, 300 kV	Operational since 2015
Titan Krios II	Cryo-EM, cryo-ET	80, 120, 200, 300 kV	Operational since 2016
Titan Krios III	Cryo-EM, cryo-ET	80, 120, 200, 300 kV	Due online in 2017
Titan Krios IV	Cryo-EM, cryo-ET	80, 120, 200, 300 kV	Due online in 2017
Talos	Cryo-EM, cryo-ET	200 kV	Operational since 2016
Scios	Cryo-SEM, Cryo-FIB	3 to 30 kV	Operational since 2017
JEOL ARM200F	EDX, EELS, atomic scale STEM imaging, electron diffraction	80 and 200 kV	Operational since 2017
JEOL ARM300F	Atomic scale TEM and STEM imaging, electron diffraction	30, 60, 80, 160, 200, and 300 kV	Operational since 2017

Science Highlights

Malarial breakout
How malaria parasites escape from red blood cells.

Depth-profiling spintronic materials
Quantifying the crossover from surface to bulk properties in important spintronic materials.





Thermally stable vaccines
The encasing of proteins in silica to improve their thermal stability.

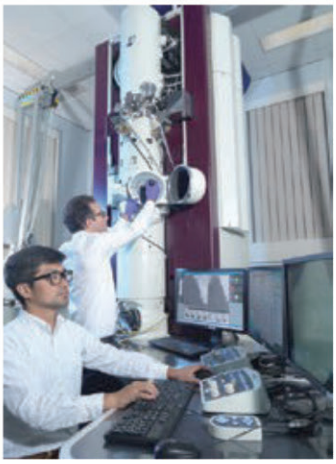
Looking at cloud formation
Investigating the reactivity of organic aerosol films.

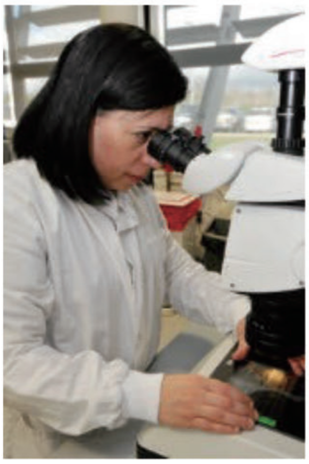
Diamond Light Source

Integrated Facilities & Future Developments

At the end of the 2019/20 Financial Year, there were 31 operational beamlines, with a total of 33 due to be operational before the end of 2020.

The construction of the Electron Microscopy Facility is a particularly interesting development for Diamond, as it will combine three different elements – the Hard X-ray nanoprobe beamline (I14), an electron imaging centre for biology, and an electron microscopy centre for physical sciences – under one roof. The new facility is the first project at Diamond that seeks to co-locate both synchrotron and non-synchrotron facilities. This physical proximity will create new synergies in efforts to tackle common problems in image analysis and sample handling; what's more, the novel set up demonstrates Diamond's evolving approach to the services it provides.





ePSIC (electron Physical Science Imaging Centre) is a new and world class facility based on the Diamond site. It is as a result of the collaboration between Johnson Matthey, Oxford University and Diamond Light Source. The centre is part of the Hard X-ray Nanoprobe beamline (I14) and the electron microscopy centre at Diamond, collectively providing unrivalled expertise and instruments. Dedicated to the physical sciences, ePSIC provides a 300 kV electron microscope, an energy-dispersive X-ray (EDX) and electron energy loss (EELS) spectroscopy microscopes.

Web : www.diamond.ac.uk
Email: diamond.comms@diamond.ac.uk

eBIC is a state-of-the-art facility at Diamond that allows scientists to explore complex biological systems in unprecedented detail via the use of six powerful cryo-electron microscopes (cryo-EM), exploiting the latest technology and software rarely available at home laboratories. Diamond was the first synchrotron facility to house and operate this type of microscope. It has set the trend with many facilities following suit.

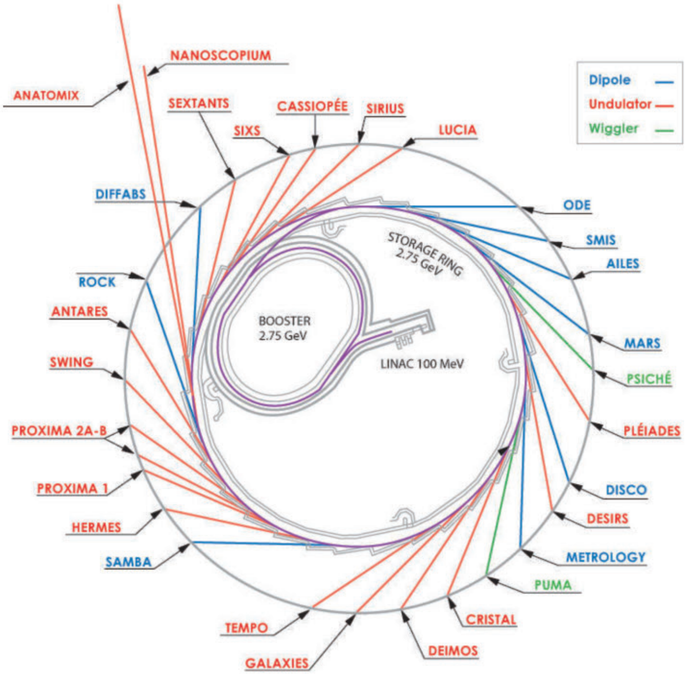
Every year is an exciting one at the Membrane Protein Laboratory (MPL) with so many positive results and amazing collaborations. Over the past years, the MPL has become a well-established user facility providing a state-of-the-art pipeline from protein production to high throughput protein crystallisation for the membrane protein structure determination community. Its proximity to Diamond's beamlines has greatly facilitated excellent working relations and collaborations between the beamline scientists, and both the MPL staff and users. Today, more than 18 membrane protein structures are as a result of the MPL and more than 30 publications acknowledge the use of the facility.

The XFEL Hub established at Diamond, is a centre for expertise in every aspect of XFEL experiments. Funded by the Wellcome Trust and the Biotechnology and Biological Research council (BBSRC), the UK-XFEL Hub provides support in technical development, including sample preparation, delivery systems and data analysis. The Hub actively supports the UK community in making full use of the transformational potential of all available XFELs in order to produce the best science.

Synchrotron SOLEIL

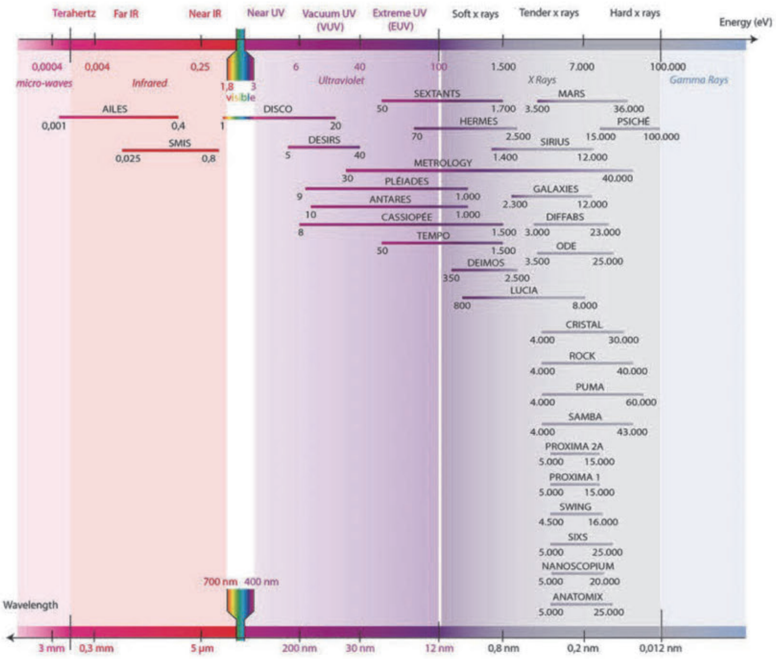
General Information

SOLEIL is a third-generation radiation facility located within the Paris-Saclay scientific and technological cluster, 20 km south of Paris. It is run as a French civil company founded by two major French public research institutes, CNRS and CEA. Construction for SOLEIL started in 2003 and it welcomed its first users in 2008.



One unique feature of SOLEIL is the continuous wide energy range covered by its 29 beamlines, from far-infrared (THz) to hard X-ray (100 keV), optimized for the soft X-ray range.

- **2.75 GeV electrons**
- **354 m storage ring**
- **29 beamlines**



Key figures for 2016

- **4300 users**
- **608 scientific publications**
- **24-hour operation, 6 days a week, 5000h/year for beamlines**
- **4 operating modes, including 3 time-structured modes**
- **500 mA and Top-up in the 4/4 mode**
- **350 permanent staff**
- **3300 visitors**

In addition to the SOLEIL beamlines, users have access to sample preparation and instrumentation laboratories supporting the following areas: chemistry, biology, high pressure, ancient materials, surfaces and microfluidics.

Synchrotron SOLEIL

Societal Impact and partnerships

SOLEIL is a highly multidisciplinary large-scale infrastructure. The research conducted in the facility by our thousands of users and staff researchers benefits many fields, such as health and medicine, environment, agrosciences, chemistry, and energy.

The number of publications in peer reviewed journals per year was over 600 in 2016 and has already reached 514 as of September 2017.

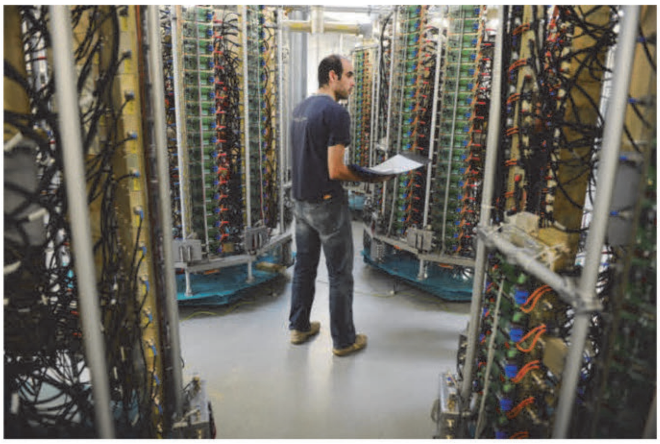
SOLEIL's 29 beamlines allow complementary experiments with a high level of user support for a deeper understanding of complex scientific challenges. The facility continuously strives to improve its performance, using the powerful synchrotron radiation tool to develop exploratory methodologies, to meet scientific requirements and constraints, and to drive new benefits for society.

Furthermore, as an accelerator for innovation, growth, and business competitiveness, SOLEIL provides manufacturers and industry service providers with advanced skills and high-performance equipment.

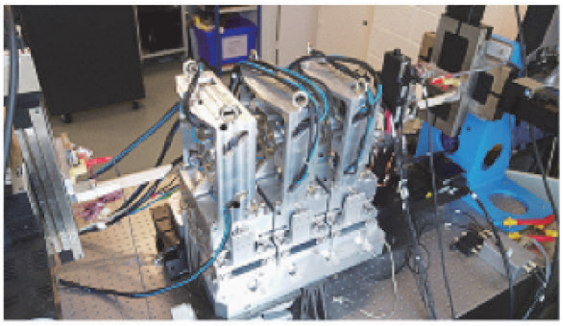
SOLEIL also involves scientific instrumentation companies in its technological research, both upstream within the framework of collaborative projects and downstream in the industrial and commercial exploitation of innovative devices designed by its teams.

In 2016, a new type of partnership was inaugurated, with a French private pharmaceutical company building a laboratory on SOLEIL's premises. This company has become the first industrial group to benefit from great proximity to our beamlines dedicated to the crystallography of macromolecules.

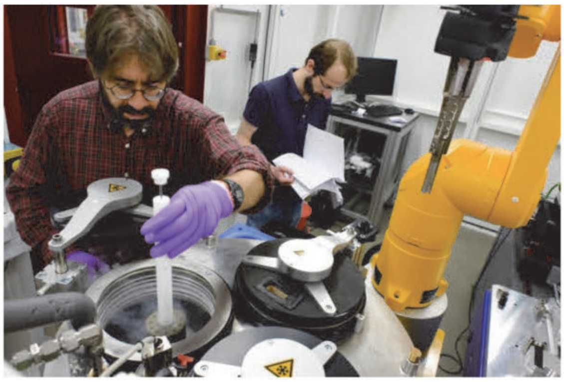
SOLEIL's work with industrial and service companies is increasing. The acceleration of industrial requests for synchrotron analysis services continued in 2016, with growth relative to 2015 of 31% in the number of industrial projects and of 45% in terms of synchrotron beamtime and income generated by these services. Activities in 2016 achieved new records for industrial use of the beamlines and laboratory facilities at SOLEIL: the international portion of industrial services was nearly 25% and the portion of services dedicated to SMEs was 27% of the overall French activity.



Towers of Solid state amplifiers, which power the accelerating cavities cryomodules of SOLEIL's storage ring, This technology was transferred to a French company.



R&D collaborative project with French industry: magnetic bench (pulsed wire) for the measurements of an original concept of hybrid permanent magnet based quadrupole.



PROXIMA-2A, one of our beamlines dedicated to crystallography of bio-macromolecules used by pharmaceutical companies.

Since January 2008, the main industrial sectors using synchrotron analysis services have been: pharmacy (41%), chemistry and petro-chemistry (16%), cosmetics (14%), biotechnology (13%), and materials (9%).

Synchrotron SOLEIL

Societal Impact and partnerships

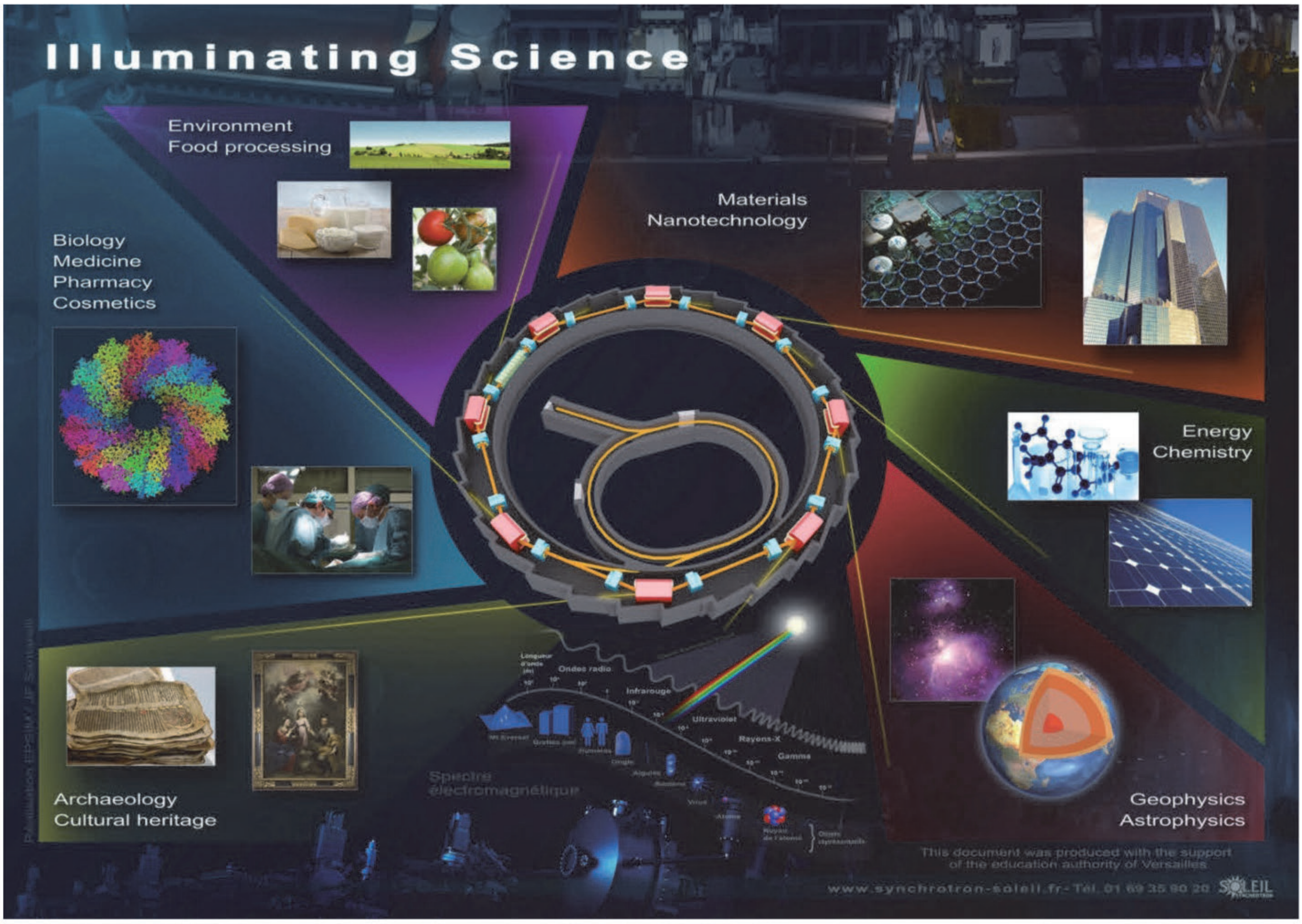
Scientific partnerships are at the heart of SOLEIL's mission. SOLEIL belongs to several networks and collaborative projects at the regional, national, and European/transnational levels.

For European projects such as CALIPSOPlus, iNext, NFFA-Europe, and IPERION-CH, SOLEIL allocates beamtime specifically to the scientific communities targeted by these projects. In addition, SOLEIL has several Memoranda of Understanding (MOUs) with other synchrotrons, in particular SPring8, as well as framework agreements with numerous research institutions and universities in France and abroad.

These agreements encourage the co-funding of masters and PhD students, staff mobility and association at SOLEIL in identified scientific and technical fields, as well as equipment sharing, loans, and exchanges. An example is the agreement signed in 2012 with the Swedish Research Council that could initiate and consolidate a strong partnership between SOLEIL and the future Swedish synchrotron MAX IV through six projects of interest, including transfer of know-how and development of instrumentation.

Some of our latest publications concerning our partnership with INRA (Institut National de la Recherche Agronomique), our Science Highlights and SOLEIL's magazine. All are available on www.synchrotron-soleil.fr

Direct contact with the public, in whatever format, remains at the core of SOLEIL's communication activities. SOLEIL receives near daily groups of visitors, aged from 12 to 99, with around 4000 people visiting every year. SOLEIL also works in close collaboration with education authorities and teachers to bring science into classrooms, ranging from primary schools to universities.



Synchrotron SOLEIL

Future Activities

New concepts in accelerator technology enable the design of photon sources with unprecedented brilliance and coherence. In particular, the so-called Diffraction Limited Storage Rings (DLSRs) have the potential to revolutionize the research which can be performed at synchrotron facilities and to serve a very broad science base in both fundamental and applied research.

SOLEIL is now starting the preliminary studies for such an upgrade, aiming to preserve the current facility's defining feature: the same wide spectral range, from infrared to hard X-rays that it offers today to scientific communities.

The increase in coherent flux will enable a much more efficient way of focusing light that will enable the investigation of complex and heterogeneous materials and systems (e.g., quantum matter, functional nanosystems, and biological tissues) at a nanometer resolution in 3D using a number of complementary probes and spectroscopies, most often combined with coherent scattering.

Such a broad range of spectroscopies will be available only at SOLEIL at this ultimate resolution, owing to the optimization of the source over a wide range of wavelengths, which has made the current facility so successful.

It is also expected that most beamlines will have multimodal capabilities, reinforcing SOLEIL's well-established strategy to offer complementary methods to address scientific problems.

Key opportunities are thus identified in the fields of life sciences, environmental sciences, energy research and the green economy, emerging technologies, and security.

Preliminary studies and prototyping could tentatively take place in 2017-2019. This would be followed by a Conceptual Design Report (CDR) in 2020 and a Technical Design Report (TDR) in 2021-2022, before starting the project aiming to see light around 2026.

ESRF – The European Synchrotron

The ESRF in a nutshell

The ESRF is a centre of excellence for fundamental and innovation-driven research in condensed and living matter science. It owes its success to the international collaboration of 22 countries, all driven by the same goals of enabling pioneering synchrotron science to tackle societal challenges that are too complex to be solved by one country alone. Each year, 10,000 researchers come to the ESRF to carry out frontier research in areas such as health, environment, sustainable and innovative materials for industry, humanity and cultural heritage.

Thirty years ago, the ESRF made history with the first third-generation synchrotron light source. Today, thanks to the support of its 22 partner countries, the ESRF continues pioneering synchrotron science with a major upgrade project called Extremely Brilliant Source (EBS), which aims to launch a brand-new generation of high-energy synchrotrons, in August 2020. EBS is a 150 M€ ESRF upgrade programme over 2015-2022, highlighted as a landmark in the ESFRI (European Strategy Forum on Research Infrastructures) roadmap and centred around the construction of a brand-new synchrotron source. State-of-the-art beamlines, an advanced instrumentation programme and a data-management implementation plan complement the programme.

ESRF – some key figures
6 GeV, 200 mA, time structured filling modes
10 000 user visits per year
~ 2 000 Publications per year in peer reviewed journals
34 000 publications over 1994 - 2019
1 700 Scientific Proposals received per year
315 783 (288.2 years) shifts delivered in 25 years
~90 M€ Operation budget per year
330M€ Upgrade Programme investment over 2009-2022
44 beamlines, with 4 new flagship beamlines by 2024

Based on scientific excellence, the ESRF X-ray science programme lines up with Horizon Europe challenges and aims to address global challenges facing our society:

- Health, health innovation, and overcoming cancer and neuro-degenerative diseases
- Materials for tomorrow and innovative and sustainable industry
- Clean energy transition, sustainable energy storage and clean hydrogen technologies
- Planetary (terrestrial and extra-terrestrial) material research
- Environmental and climatic challenges, water supplies and earth atmosphere
- Bio-based economy and food security
- Humanity and world cultural heritage

ESRF – The European Synchrotron

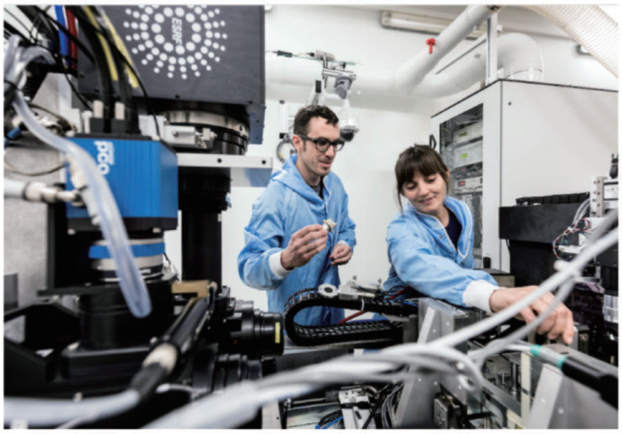
The Societal Impact of the ESRF

The primary return of the ESRF to society is scientific and technological knowledge, which is shared by the whole scientific community and in particular by researchers from partner countries. All inventive research carried out at the ESRF propagates to society and impacts the scientific cultures and the economies of its member states and beyond. Moreover, industry strongly benefits from and supports fundamental research using the ESRF.

Since 1988, the ESRF has returned contracts to commerce and industry totalling more than €2bn. This feeds directly and indirectly into the economies of partner countries, for example through training and capability building in education and industry.

ESRF's missions

• Design, construct, operate and develop state-of-the-art X-ray synchrotron instruments to the benefit of the scientific communities of the Member and Associate countries
• Serve the international community for the advancement of knowledge and to address global societal challenges
• Support the use of X-rays by industry from Member and Associate countries to strengthen its competiveness in the global scale
• Train the next generation of scientists, engineers and technical staff

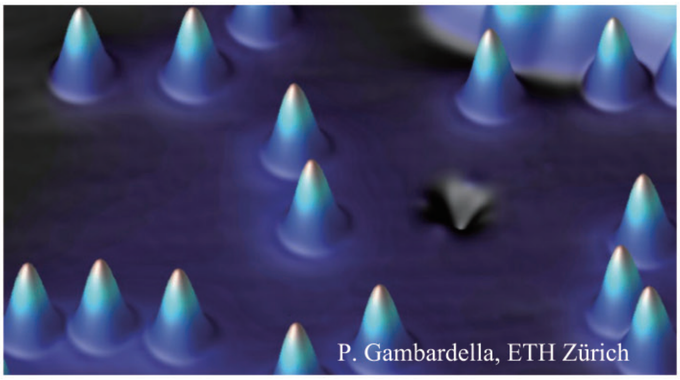


The research programmes carried out at the ESRF rely on an impressive number of young researchers, PhD students and post-doctoral fellows.
In addition to training highly skilled staff, the ESRF has a strong track record in disseminating synchrotron methods and techniques to other facilities.

With EBS, the implementation of the first high-energy fourth-generation synchrotron, the ESRF is providing its partner countries and the international synchrotron community with new technologies to push the limits of material research and to establish together a new chapter for synchrotron science.

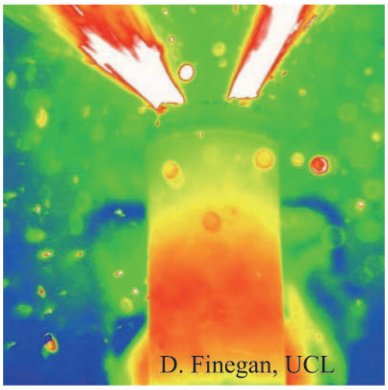
Current research: addressing global challenges

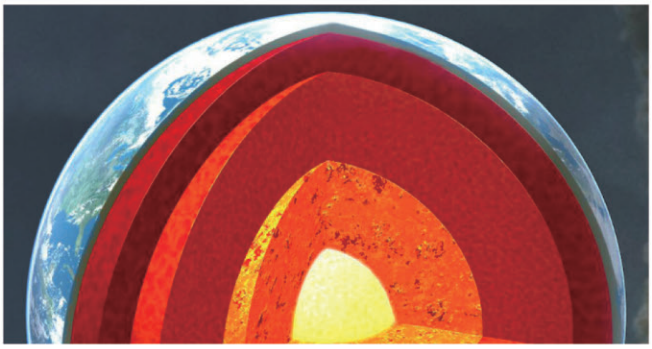
Understanding the living world to better combat diseases
The origin of Alzheimer's disease is still a mystery in 95% of cases. Scientists at the ESRF and other institutes are using a variety of techniques to try to unveil the trigger of this devastating disease. Other user groups are studying the problem of antibiotics, some are examining the mechanisms involved, while others are striving to find alternative drugs through structural biology and rational drug design. Furthermore, developing a cure for cancer is another hot topic with important results coming from the field of therapeutic antibodies. Studies at the ESRF have revealed the mechanism of action of one such antibody that causes detection of the cancer cells by the host's immune system.


P. Gambardella, ETH Zürich

Materials for tomorrow
Researchers across the world are looking for new superconductive materials that function at less prohibitive temperatures, and would, in ambient conditions, conduct electricity with zero resistance, or allow super-fast electronics. Great hope rests on so-called high-temperature superconductors. Using pioneering resonant inelastic X-ray scattering equipment at the ESRF, scientists have revealed a new property of these materials: the presence of a variety of charge density waves called dynamical charge density fluctuations.

Materials for energy production and storage
Batteries are the focus of many user groups, with studies ranging from the explosive behaviour of short-circuited commercial batteries to the development components and even of alternatives such as LiS-based technologies. ESRF users and staff are also studying working proton exchange membrane fuel cells (PEMFC) to understand their functioning and to reveal details that cannot be seen by other means. The insight gained from research into these promising energy materials will help develop safer batteries, more efficient and longer lasting fuel cells, and less polluting energy alternatives for the future.


D. Finegan, UCL

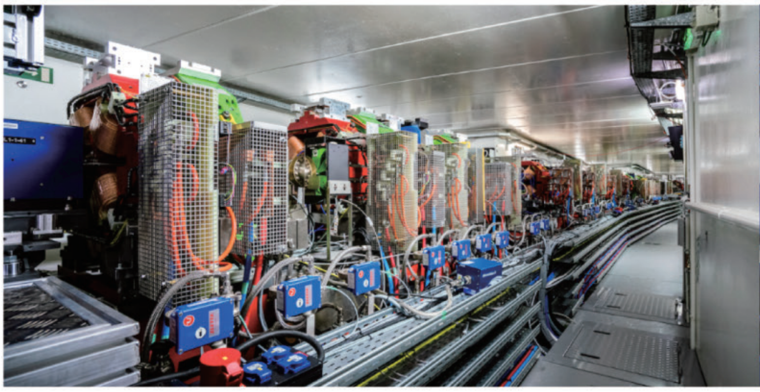


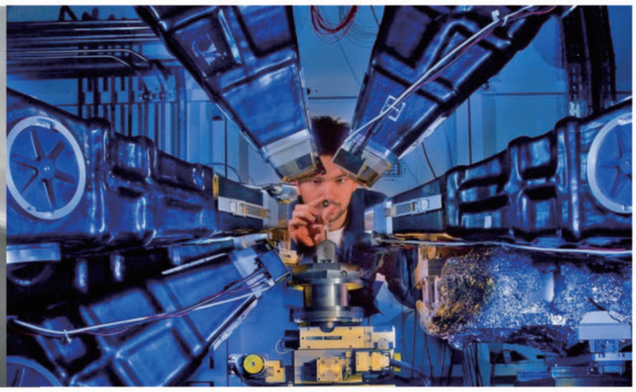
Looking into our planet: on the origin of diamonds
ESRF users have gained insight into the carbon cycle reaching into the Earth's mantle by studying iron carbonates under extreme conditions of pressure and temperature. They identified a plausible mechanism for the transport of carbon down into the mantle, which helps explain the occurrence of diamond inclusions. Extreme conditions research also lets users discover new materials with advanced properties.

ESRF – The European Synchrotron

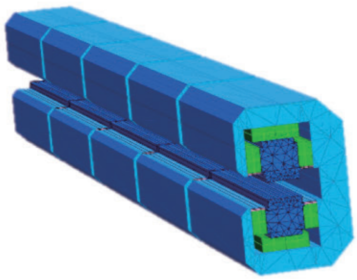
The ESRF is implementing a brand-new generation of high-energy synchrotrons

In 1994, the ESRF was the first third generation synchrotron source entirely based on IDs to become operational. Today, with the Extremely Brilliant source project (ESRF-EBS), the ESRF continues to lead the way by opening in August 2020 the first high-energy fourth-generation synchrotron light source, with performances multiplied by 100 in terms of brilliance and coherence. Highlighted as a landmark on the Roadmap of the European Strategy Forum on Research Infrastructures (ESFRI), ESRF-EBS represents an investment of 150 M€ over the period 2015-2022.





EBS relies on an important number of key innovative technologies and solves a decades-long puzzle for the implementation of stable and highly performing diffraction-limited high-energy storage rings. **The new and original EBS concept is based on a Hybrid Multiple Bend Achromat (HMBA) lattice design, which is now paving the way to a new generation of synchrotrons worldwide.** The new lattice will improve the brilliance of the ESRF light source by a factor of 100 while fulfilling the constraint to keep the original beam line structure, thanks to an innovative magnet design.



Permanent magnet prototypes for the new ring

The EBS will not only replace the existing storage ring with the new EBS low-emittance storage ring, but it also includes:

- **an ambitious X-ray detector programme**
- **a data management strategy.**
- **4 new flagship beamlines**

For Serial Macromolecular Crystallography
For Hard X-ray Diffraction Microscopy
For Coherent X-rays Dynamics & Imaging Applications
For High throughput Large Field Phase-contrast Tomography

EBS efficiently re-uses 90% of previously existing infrastructure, and thus addresses best practices to lower the ESRF carbon footprint.

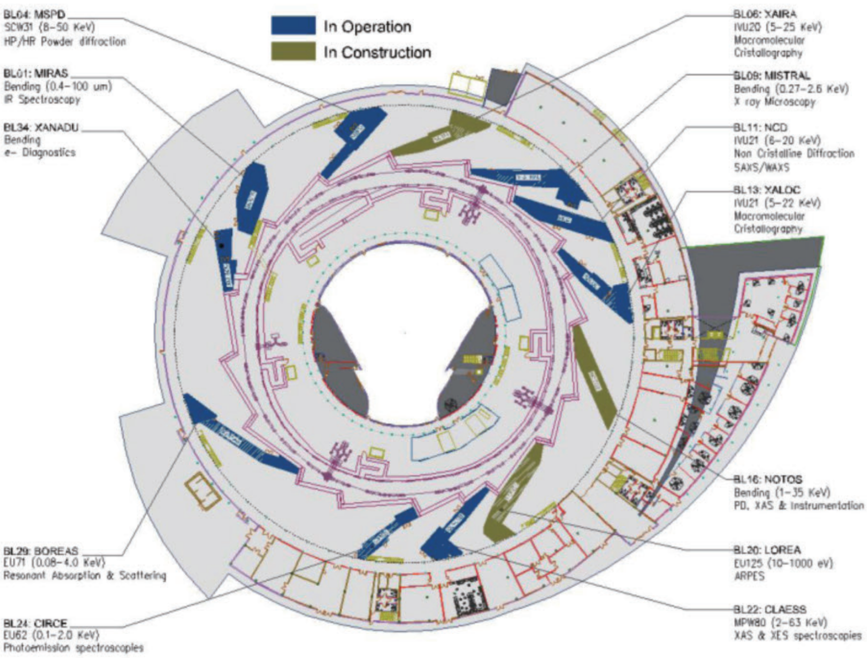
The enhanced X-ray performances of EBS will provide new tools for the investigation of materials and living matter from the macroscopic world down to the nanometre scale, and hopefully to the direct imaging of conglomerates of a few atoms. It will thus allow scientists to probe complex materials in greater detail, with higher quality, and much faster, sparking new research opportunities in fields such as health, environment, energy, innovative and sustainable materials.

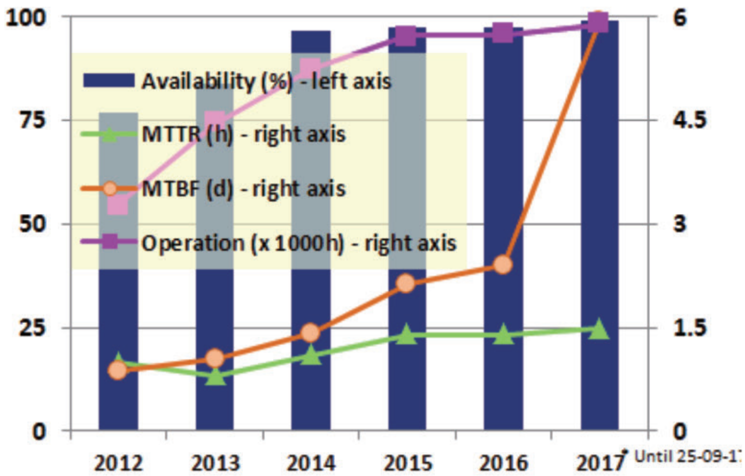
ALBA Synchrotron

General Information

www.albasynchrotron.es

- User operations: started in 2012
- 3 GeV 250 mA Top-Up operations within 1% current variation
- 5912 h of operation with 4680 h user time. Availability at the level of 98.2% during 2018.
- Operation Budget: 24M€ in 2017 FY
- In FY 2018, welcomed 2109 visiting users
- Proposals have grown from about 200 in 2012 to almost 535 in 2019. Average Overbooking Factor: 1.9.
- User affiliation: 281 granted proposals in 2019, 167 national, 114 international
- Number of publications in refereed journals: 1625 total since 2012, 234 publications with beamtime in 2019
- Eight beamlines in operation, four under construction, three in the approval process





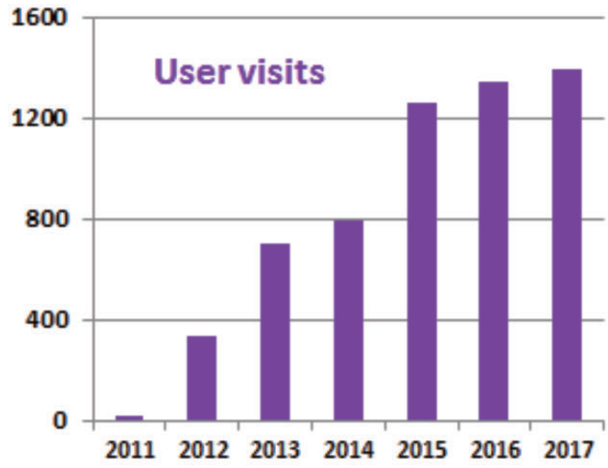
ALBA Synchrotron

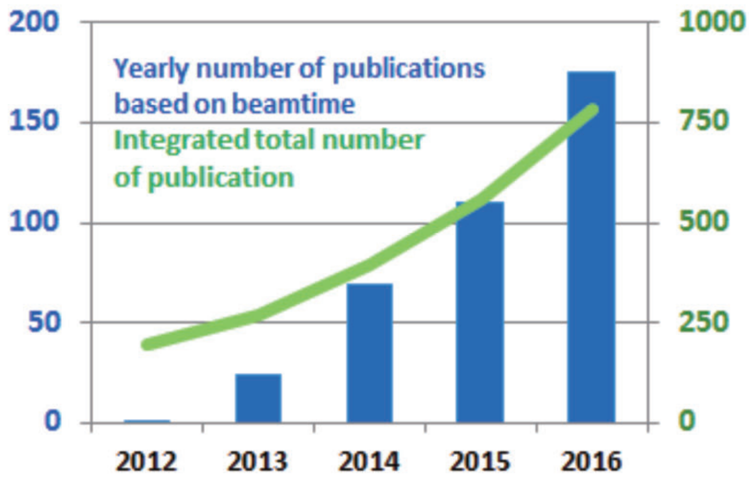
Current Activities

ALBA is an instrument for providing solutions to societal challenges, from health to energy production and storage, from environmental challenges to communication advances, from understanding our cultural heritage to preserving it. It is a Third Generation Synchrotron Radiation (SR) facility located in Cerdanyola del Vallès, Barcelona, Spain, operated by the CELLS Public Consortium. It is jointly owned and financed by the national and regional governments.

ALBA was designed from 2003 to 2006. Construction and commissioning were completed in the following six years, with user operations starting in 2012.

Its heart is the accelerator complex, which is composed of an injector (a 3GHz Linac plus a full energy Booster) and a 3 GeV Storage Ring (SR). The nominal e-beam intensity in the SR is 250 mA and the horizontal emittance is 4.4 nmrad. Surrounding the accelerator, the beamlines exploit the synchrotron light capacities of probing matter, with each beamline specialized in a different technique based on one of the variety of interactions between light and matter. Several ancillary laboratories, available for operation and maintenance of the infrastructure and for collaboration, complete the installation.





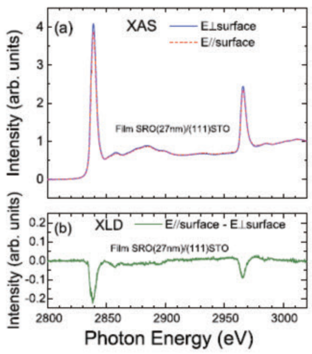
ALBA

- serves a large community of users: about 6000 researcher visits and 1000 experiments have been recorded to-date
- has contributed to the rapid increase in the Spanish synchrotron light user community by an order of magnitude following the project's approval, while attracting competitive international users, which today account for more than one third of the total; an ever increasing output of scientific publications, with a high average impact factor (18% of publications with IF>7) testifies to the excellence of the facility
- guides the development of the industrial user community
- provides an effective outreach program towards society with more than 7000 visitors per year
- has established a student training program for university and dual vocational training students
- contributes to fostering high technology companies
- serves as one of the nodes of the international network of photon sources and maintains fruitful collaborations with other Spanish research facilities

Specialty examples and beamlines

XMCD at high energies

XMCD (X-ray Magnetic Circular Dichroism) is a key tool for magnetic studies of thin layers, nanostructures, surfaces, and interfaces. Computing, magnetic memories, sensors, and a large number of devices utilize magnetism as a basic principle of their operation. The BOREAS BL, which is equipped with a shallow angle blazed grating in the monochromator, produces monochromatic high photon flux up to 4000 eV.

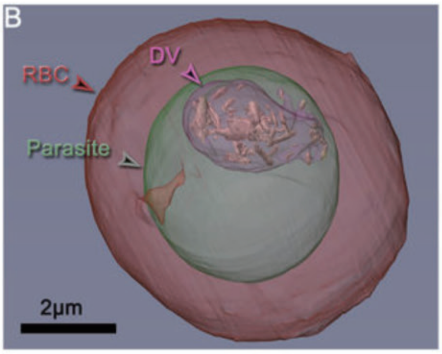


a) X ray absorption spectra at the Ru L_3 and L_2 absorption energies from a 27 nm ferromagnetic film of $SrRuO_3$ grown on $SrTiO_3$. b) Linear dichroism spectrum obtained subtracting the two spectra in (a). /doi.org/10.1103/PhysRevB.91.075127

Soft X-ray Transmission Microscopy

High-resolution three-dimensional imaging of biological cells is one of the key tools in cellular biology, allowing visualization of cells' inner morphology under different conditions. The Cryo soft X-ray full-field microscope, MISTRAL, allows the imaging of cells with high resolution 3D maps (around 50 nm).

It also provides a tool for characterizing magnetic materials, allowing high-resolution visualization of features such as magnetic domains and vortices.

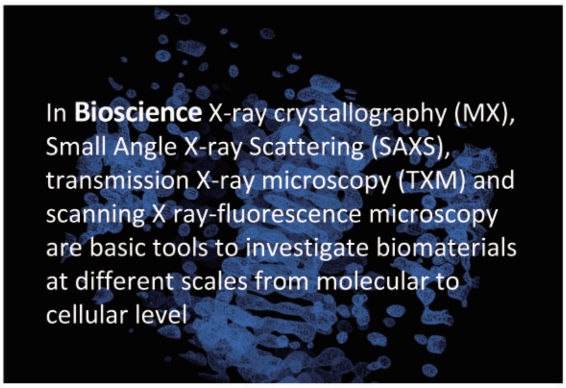


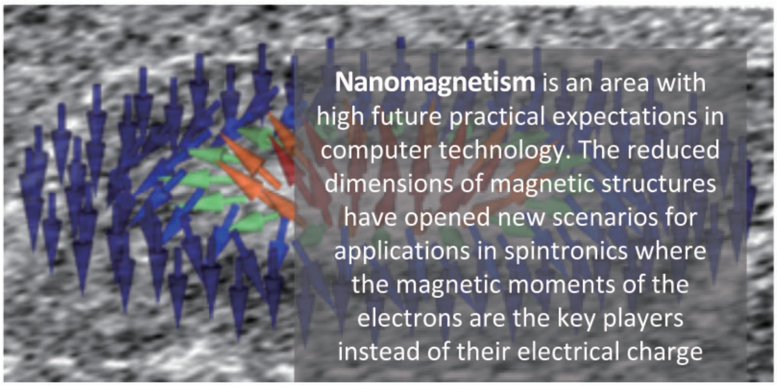
Reconstruction of a blood cell infected by the malaria parasite, obtained in the soft X-ray microscope, operated at 520 eV doi:10.1038/s41598-017-00921-2

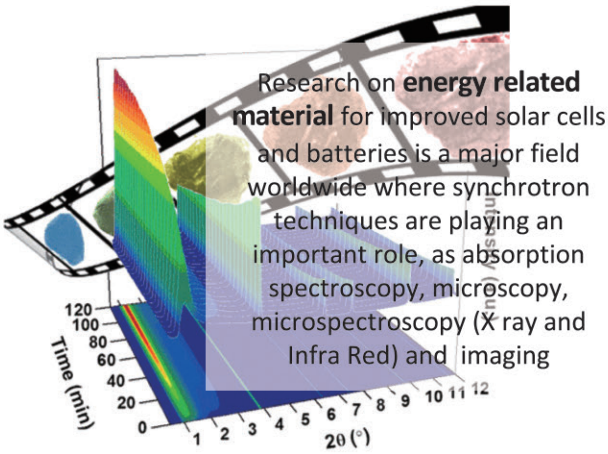
Port	Beamline	Phas.	Op. Start	Source / Endstation	Energy /	Experimental techniques	Key scientific fields
1	MIRAS	II	2016	BM	IR: 10-100 μm	Spectroscopy, imaging	Biosciences, Material science, Cultural heritage
4	MSPD	I	2012	SC Wiggler/ HRPD	8 - 50 keV	High resolution powder diffraction	Material science
		I	2012	SC Wiggler/ HRPD	8 - 50 keV	Microdiffraction & High pressure diffraction	Material science, Cultural heritage
9	MISTRAL	I	2012	BM	270 - 1200 eV	Cryo nano-tomography	Biosciences, Nanomagnetism
11	NCD	I	2012	IV undulator	6.5 - 13 keV	SAXS & WAXS	Biosciences, Materials science
13	XALOC	I	2012	IV undulator	5 - 22 keV	Macromolecular crystallography	Biosciences
22	CLAESS	I	2012	MP wiggler/ XAS	2.4 - 63.2 keV	Absorption spectroscopy	Materials science, Catalysis
		I	2016	MP wiggler/ XES	6.4 - 12.5 keV	Emission spectroscopy	Environmental sciences, Electronic structures
24	CIRCE	I	2012	APPLE undulator/ PEEM	100 - 2000 keV	Photoemission electron microscopy	Nanomagnetism, Surface science, Materials science
		I	2014	APPLE undulator/ NAPP	100 - 2000 keV	Near ambient pressure photoemission	Catalysis, Surface science, Materials science
29	BOREAS	I	2012	APPLE undulator/ HECTOR	80 - 4000 keV	Absorption Spectroscopies, XMCD, ...	Nanomagnetism, Surface science
		I	2015	APPLE undulator/ MARES	80 - 4000 keV	Scattering, imaging	Nanomagnetism, Surface science
20	LOREA	II	2018	APPLE undulator	10-1000 eV	Angle-resolved Photoemission Spectroscopy	Advanced materials, 6band structure determination
6	XAIRA	III	2018	to be determined		Microfocus beamline for Macromolecular crystallography	Biosciences
16	NOTOS	III	2019	to be determined		X-ray absorption and diffraction, Instrumentation development and Innovation	Materials Science, Chemistry, Instrumentation

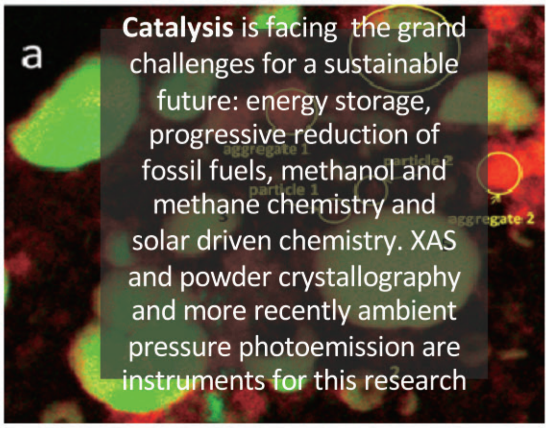
ALBA Synchrotron

Scientific Priorities and Future Perspectives









The main objectives for the period 2017-20 are:

- to maintain and, where possible, to improve the excellent performance indicators reached over the first several years of operation
- to complete the new beamline construction projects
- to enhance ALBA capabilities based on the four strategic scientific priorities in line with H2020 European societal challenges and in collaboration with the user communities
- to serve as the host for ancillary centers, e.g., an advanced microscope center
- to start mapping the evolution of the facility over the next decade, to maintain competitiveness in the photon source world
- to strengthen the potential for innovation with focused programs for industry
- to foster the development of scientific communities in less-advanced countries through dedicated partnerships
- to contribute to the education of a gender-balanced knowledge-based society and to raise public and political awareness of the need for scientific investments that will benefit the future of our world

Paul Scherrer Institute: Swiss Light Source & SwissFEL

General Information: http://www.psi.ch/sls & http://www.psi.ch/swissfel

SLS key numbers user operation 2016
User operations: started from **2001**

User Operation	2016
Visitors (badge requests)	3134
Individual Users	1673
Experimental days	1958
Number of Experiments	1037
New Proposals	718
Number of Publications (in total)	620
High Impact Publications (≥ 7.1 (PRL))	185

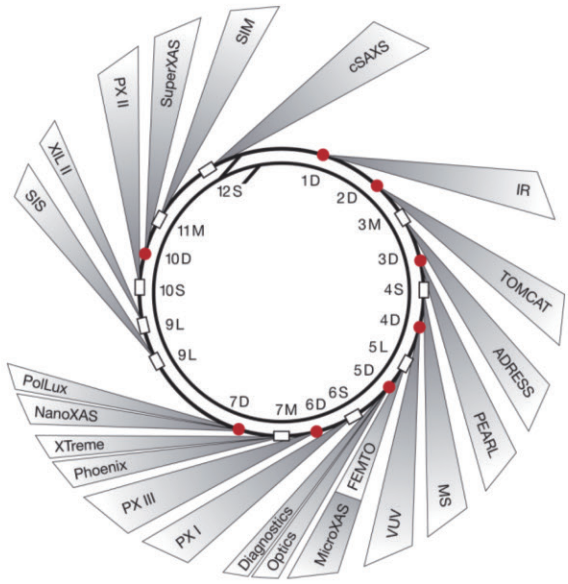
SLS-Accelerator: 2.4 GeV, 400 mA top-up operation within 0.5 % current variation.

Total beam time: 6,864 h; 5,016 h user operation + 800 h beamline commissioning.
Mean time between failure: 193 h (2016).

Synchrotron Radiation and Nanotechnology

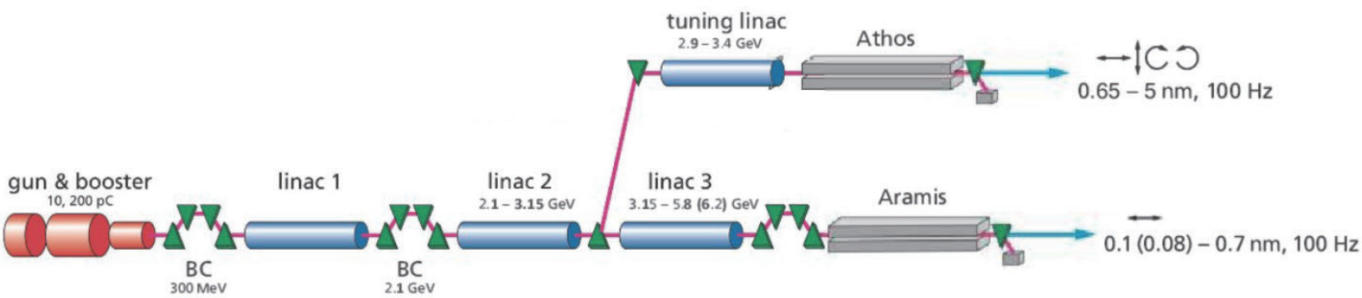
Paul Scherrer Institute (PSI) has two light sources, the Swiss Light Source (SLS) and SwissFEL, putting the old adage 'Seeing is believing' into practice. Being one of the world's most brilliant X-ray sources, PSI light sources enable researchers to investigate matter on a length scale of nanometers and time scales down to femtoseconds. Its facilities for X-ray diffraction, imaging and spectroscopy essentially attract researchers from all scientific disciplines. Having started operation in 2001 with four beamlines, SLS has now sixteen beamlines.

Beamline Map: 16 beamlines are in operation.



SwissFEL Facts and Figures

- **ARAMIS (phase I):** 1-7 Å hard X-ray SASE FEL, Seeded operation, In-vacuum , planar undulators with variable gap. User operation 2019.
- **ATHOS (phase II):** 6.5-50 Å soft X-ray FEL for SASE . Seeded operation . APPLE X undulators with variable gap and full polarization control. User operation 2021.

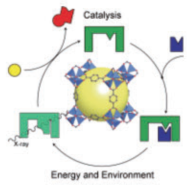


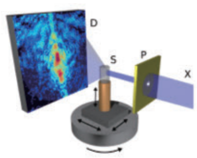
Paul Scherrer Institute: Swiss Light Source & SwissFEL

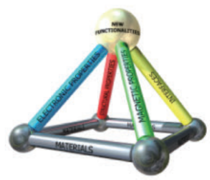
Current Activities

Swiss Light Source

The SYN-department comprises four laboratories. Three laboratories (LSF, LSB, LSC) are centered around the Swiss Light Source (SLS). The fourth is the Laboratory for Micro- und Nanotechnology (LMN).



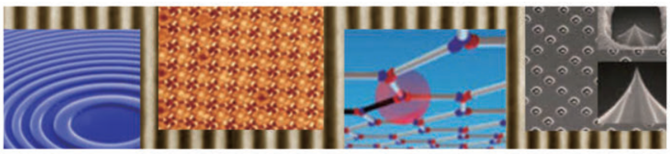




LSF: Two of the grand challenges of the 21st century are energy and sustainability. Within the LSF, we combine synthetic chemistry with development and application of new synchrotron-based characterization tools to contribute to solving these challenges.

LSB: In something as complex as a human being structures and processes occur on all length scales from macroscopic down to atomic dimensions. The SLS host a variety of techniques to address problems on different length scales.

LSC: Materials with new, functional properties are the scope of intense research, since they offer fascinating insights into fundamental interactions and hold promise for advanced technologies which is highly needed. The SLS host world-leading capability in advanced materials spectroscopy ranging from photoemission spectroscopy, over spectromicroscopy to different X-ray absorption, scattering and diffraction techniques. These techniques enable to provide the society with fundamental knowledge needed for the next generation technologies



LMN is dedicated to fundamental and applied research. We focus on outstanding nanoscience by exploiting the synergies between advanced micro/nanofabrication and PSI's large scale facilities, in particular the Swiss Light Source (SLS). We enable innovations in instrumentation (optics, detectors, diagnostics etc.) for large scale facilities by applying nanotechnology. A further focus is to provide advanced micro- and nanofabrication technologies to academic and industrial users, in particular in the area of polymer nanotechnology.

SwissFEL

ARAMIS scientific priorities

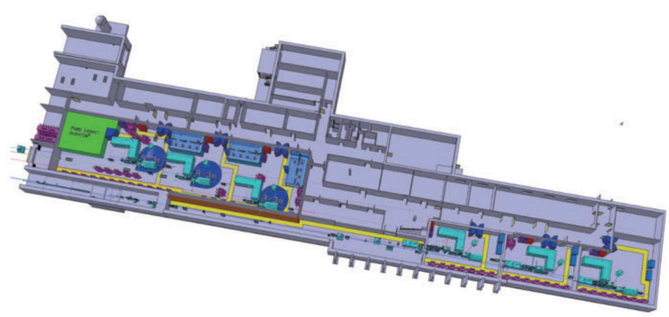
t-resolved chemistry:
charge-transfer reactions
catalytic rearrangements
photo-chemistry
liquid-jet injection and single-shot spectroscopy at **Alvra**

t-resolved solid-state dynamics:
photo-induced phase transitions
ordering dynamics
coupled degrees of freedom
scattering from cryogenic thin films at **Bernina**

membrane protein structure:
3D nano-crystal SFX in LCP at **Alvra**
supported 2D crystallography at **Bernina**

SwissFEL stresses:
potentially high-impact fields of local interest, for which the machine is competitive.

Technical considerations
100 Hz repetition rate: optimal for refreshed solid and liquid samples, LCP injection , large array detectors
10 fs time resolution, high-field THz pump:
ultrafast dynamics with pump-probe spectroscopy and scattering
3-7% broad bandwidth mode:
many reflections per shot in Laue crystallography
single-shot spectroscopy (L_2 and L_3 edges simultaneously)
2-5 keV:
strategic regime for catalysis



ATHOS Exp. surface:1 single hutch
ARAMIS Exp. surface: 3 separate hutches

Paul Scherrer Institute: Swiss Light Source & SwissFEL

Future Activities

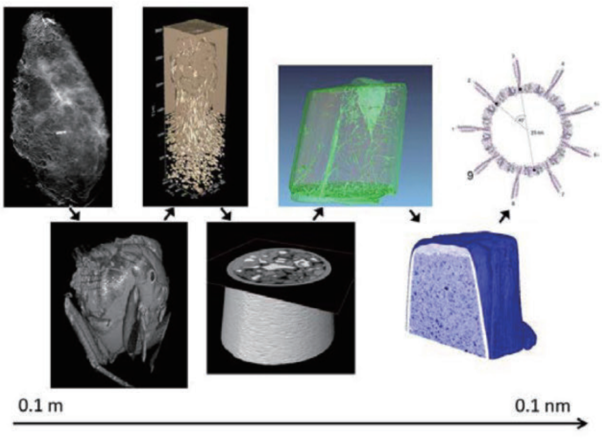
SLS has world-leading facilities for unraveling the structure of proteins, for in-depth 3D imaging of matter, and for investigating how the electrons of atoms and molecules keep matter together and render it properties such as magnetism and electron conduction at zero resistance ('superconductivity'). The beamlines for protein structure determination are intensively used by pharmaceutical companies in Switzerland and abroad. SLS is also leading in the development of pixelated X-ray detectors. The company DECTRIS has been spun off from these activities.

Of critical importance for the above studies is the brilliance of the X-ray source. Recent major developments in the technology of electron storage rings enable a great increase in the brilliance. Although SLS is already a brilliant X-ray source, it can be made even more brilliant, namely by up to two orders of magnitude.

SLS 2

By 2021, the SLS will be twenty years old. Installation of an multi-bend achromat (MBA) lattice will bring it back to the forefront of international competition for another two decades. The high brilliance combined with high flux will enable much faster imaging of extended objects than before. 4D imaging on the time scale of milliseconds will be possible. This feature will be complementary to the much faster imaging times of smaller objects at SwissFEL. SLS 2 will enable us, for the first time, to bridge the so-called 'imaging gap' between the macroscopic world and the nano-world. The much smaller beam generated by SLS 2 will also bring significant improvements to the methods by which we determine the structure of certain classes of proteins. Also studies of electron bonding in matter will benefit greatly from the new properties of the facility. For the first time it will be possible to directly measure by resonant inelastic X-ray scattering the very small energy scales that determine the properties of correlated-electron materials, e.g., superconductors.

Bridging the length-scales between 0.1 m and 0.1nm (see below): (from left) Mammogram, fly in flight, volcanic process, hardened cement paste, lacuno-canalicular network in bones and piece of catalyst, molecular structure of centriole obtained by X-ray diffraction. At SLS 2, images will be taken 20 times faster and dynamic processes will be studied on shorter time scales.



ATHOS: Extending capabilities and doubling capacities for SwissFEL

Soft X-rays : strategic importance

- **Ultrafast Magnetization Dynamics**

  What is the temporal behavior in magnetic solids?

  What is the fate of the spin angular momentum in sub-ps laser-induced demagnetization?

- **Real-time chemistry and catalysis**

  What is the sequence of bond breaking and formation in a chemical process?

  Pump-probe spectroscopy at the C, N and O resonances maps the element-specific dynamics of energy and charge transfer.

- **Spectroscopy of Correlated Electron Materials**

  How do electron correlations generate novel states of matter?

  Time-resolved diffraction and imaging at spin- and orbital-sensitive transition-metal resonances follows the energy flow between coupled degrees of freedom.

- **Non-linear X-ray science**

  What new fundamental knowledge will arise from extending non-linear optics to X-ray / X-ray interactions in condensed matter?

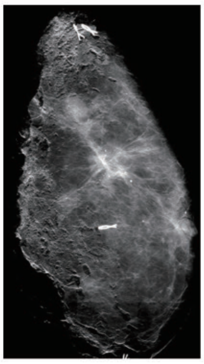
  Stimulated Raman scattering promises a vast improvement in inelastic X-ray scattering efficiency.

Paul Scherrer Institute: Swiss Light Source & SwissFEL

Synchrotron Radiation for the Future of Humanity

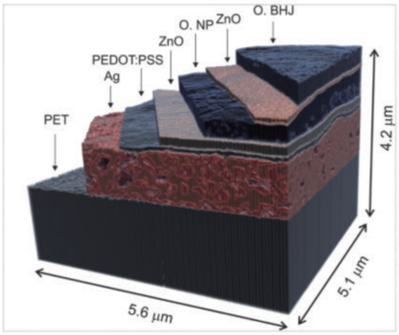
The three central scientific thrusts of the PSI are human health, energy and the environment and matter and materials. It is expected that SLS 2 and SwissFEL will have an enormous impact on all these themes. Synchrotron radiation based research has profound impact on successfully addressing grand challenges of the 21st century.
Human health is improved by understanding the basic processes of life and disease and developing early diagnosis and treatment. Green energy and industrial production are governed by the development of novel conversion devices and storage media, as well as catalysts that enable efficient synthesis and conversion. The development of advanced electronics depends on corresponding characterization techniques. Geology helps understanding fundamental processes inside our planet with direct impact on us and paleontology helps us in understanding the past and thereby getting a clearer view on potential scenarios for the future.
These research areas depend on and strongly benefit from studies utilizing synchrotron radiation and the previously sketched future activities will help covering the blind stops that still exist in our understanding of ourselves and our environment seen in four dimensions, i.e. both in space and time evolution.

Below some examples of research with synchrotron radiation for the future of humanity.



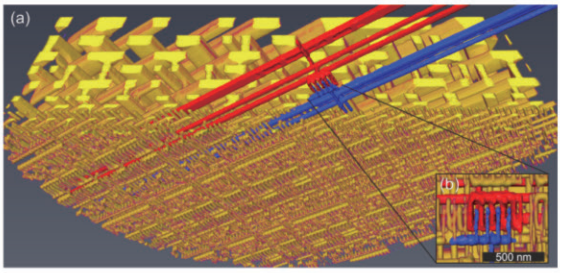
Mammography

A Study on Mastectomy Samples to Evaluate Breast Imaging Quality and Potential Clinical Relevance of Differential Phase Contrast Mammography
DOI: 10.1097/RLI.0000000000000001



X-ray nanotomography aids the production of eco-friendly solar cells

Improving organic tandem solar cells based on water-processed nanoparticles by quantitative 3D nanoimaging
DOI:10.1039/C5NR02824H



3-D X-ray imaging makes the finest details of a computer chip visible

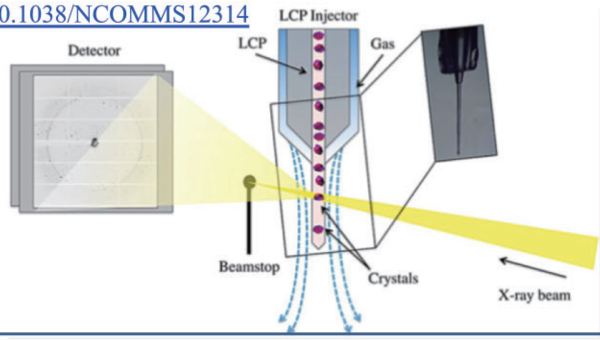
High-resolution non-destructive three-dimensional imaging of integrated circuits

DOI: 10.1038/nature21698

Serial crystallography of membrane proteins
The fundaments for structural based drug design

Lipidic cubic phase injector is a viable crystal delivery system for time-resolved serial crystallography

DOI: 10.1038/NCOMMS12314



Contact and Proposal Deadlines

Synchrotron radiation and nanotechnology (SYN)

Prof. Dr. Gabriel Aeppli, gabriel.aeppli@psi.ch

Proposals: http://www.psi.ch/useroffice/

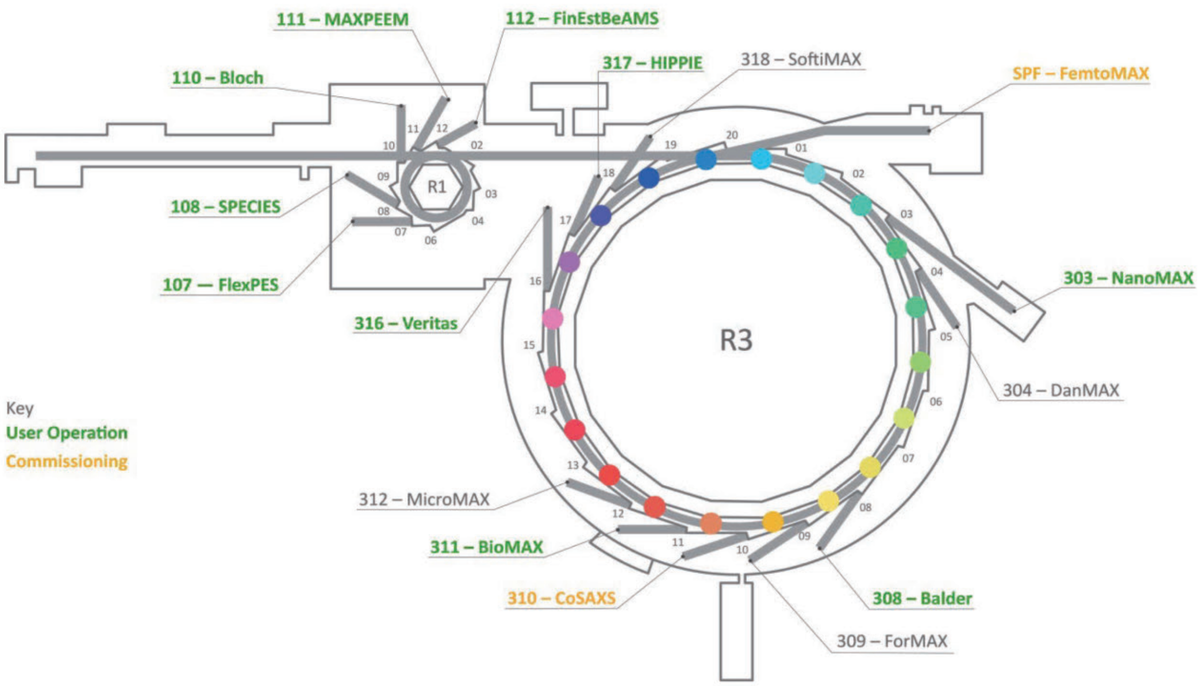
MAX IV Laboratory

General Information

MAX IV Laboratory is a Swedish national research infrastructure hosted by Lund University. MAX IV is the successor of MAX-lab and builds on three decades of successful multidisciplinary research at this facility. The MAX IV facility, inaugurated in 2016, consists of a 3 GeV storage ring, a 1.5 GeV storage ring and a linear accelerator (linac) that serves as a full-energy injector to the rings and also as the source for the short pulse facility (SPF). The 3 GeV ring is based on a novel multibend achromat (MBA) design developed by researchers at MAX-lab, providing world-leading emittance (0.3 nm rad).

Sweden has in MAX IV realised a world-class synchrotron that is considered a model by many other facilities. A basic underlying strategy of the MAX IV design is to focus each accelerator on specific needs. Thus, while the 3 GeV ring, 528 m in circumference, aims to provide high brightness hard X-rays up to about 40 keV, the 1.5 GeV ring, 96 m in circumference, is optimised to meet the needs for softer radiation, from 5–1000 eV. Moreover, the linac is equipped with bunch compressors providing ultra-fast X-ray pulses (100 fs) by spontaneous emission in the short pulse facility. The linac also allows for a future upgrade to a free electron laser (FEL).

Most planned capabilities of the MAX IV accelerator systems have been commissioned, ten beamlines are in user operation, and the remaining six funded beamlines will be in operation by 2022.



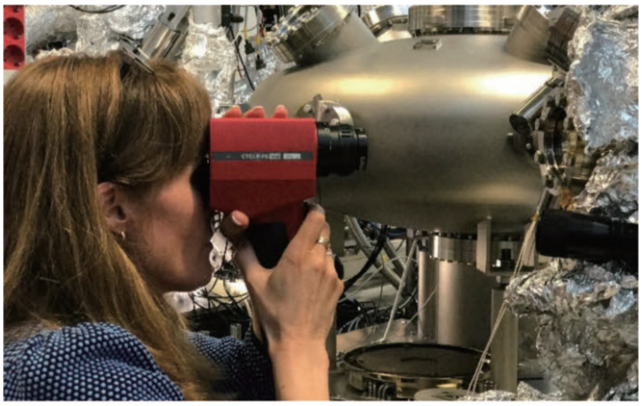
Current & Future Activities

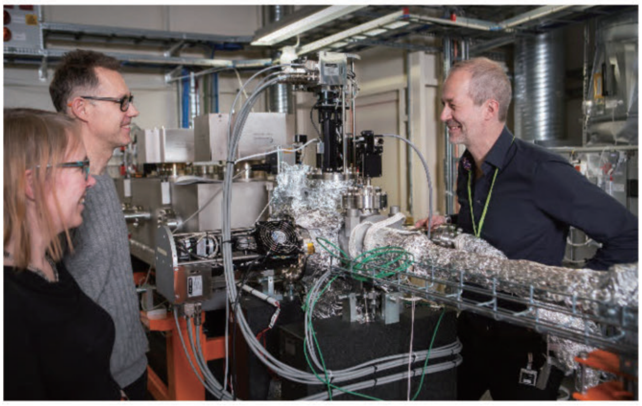
Beamline development

The MAX IV facility can accommodate up to 26 beamlines. Sixteen beamlines are currently in operation or under construction, our goal is for 20 beamlines to be so by 2026. The beamlines will serve a broad range of scientific fields from life science, chemistry, physics and environmental science to engineering, materials sciences and cultural heritage.

MAX IV will support basic research, education, innovation and industrial research. The scientific focus of all beamlines is determined in close collaboration with the user community.

The brightness and the concomitant coherence of the X-rays are properties making MAX IV unique. These properties enable high-resolution and high-sensitivity imaging, diffraction and spectroscopy, techniques that will be prioritised at MAX IV.





Currently funded beamlines at MAX IV.
Numbers correspond to those in the beamline map.

Beamline	No.	Accelerator	Technique
Balder	308	3 GeV	Hard X-ray absorption and emission spectroscopy (XAS, XES) and X-ray diffraction (XRD) with emphasis on in-situ and time resolved studies
BioMAX	311	3 GeV	Macromolecular crystallography with a high degree of automation and remote user access
Bloch	110	1.5 GeV	Angle resolved photoelectron spectroscopy (ARPES) including spin resolution (SPIN-ARPES) for studies of the electronic structure of solids and surfaces
CoSAXS	310	3 GeV	Small and wide angle X-ray scattering (SAXS, WAXS) and coherent techniques for soft matter and bio materials
DanMAX	304	3 GeV	Powder diffraction (XRD) and tomographic imaging (XTM) of hard (energy) materials
FemtoMAX	SPF	Linac	Time-resolved hard X-ray scattering (XRD) and spectroscopy (XAS) methods for studies of ultrafast processes
FinEstBeAMS	112	1.5 GeV	Electron spectroscopies and luminescence methods for studies of low density matter and solid.
FlexPES	107	1.5 GeV	Soft X-ray spectroscopies for studies of low density matter and solids
ForMAX		3 GeV	Full-field tomography, SWAXS, and scanning SWAXS imaging
HIPPIE	317	3 GeV	Near ambient pressure photoelectron spectroscopy (XPS) on solids and liquids
MAXPEEM	111	1.5 GeV	Photoelectron microscopy for investigation of surfaces and interfaces
MicroMAX	312	3 GeV	Macromolecular Serial Crystallography with a wide range of sample delivery systems, time-resolved studies
NanoMAX	303	3 GeV	Imaging with spectroscopic and structural contrast techniques on the nano scale
SoftiMAX	318	3 GeV	Scanning transmission X-ray microscopy (STXM) and coherent imaging methods
SPECIES	108	1.5 GeV	Resonant inelastic X-ray scattering (RIXS) and near ambient pressure photoemission
Veritas	316	3 GeV	Resonant inelastic X-ray scattering (RIXS) with unique resolving power and high spatial resolution

Current & Future Activities

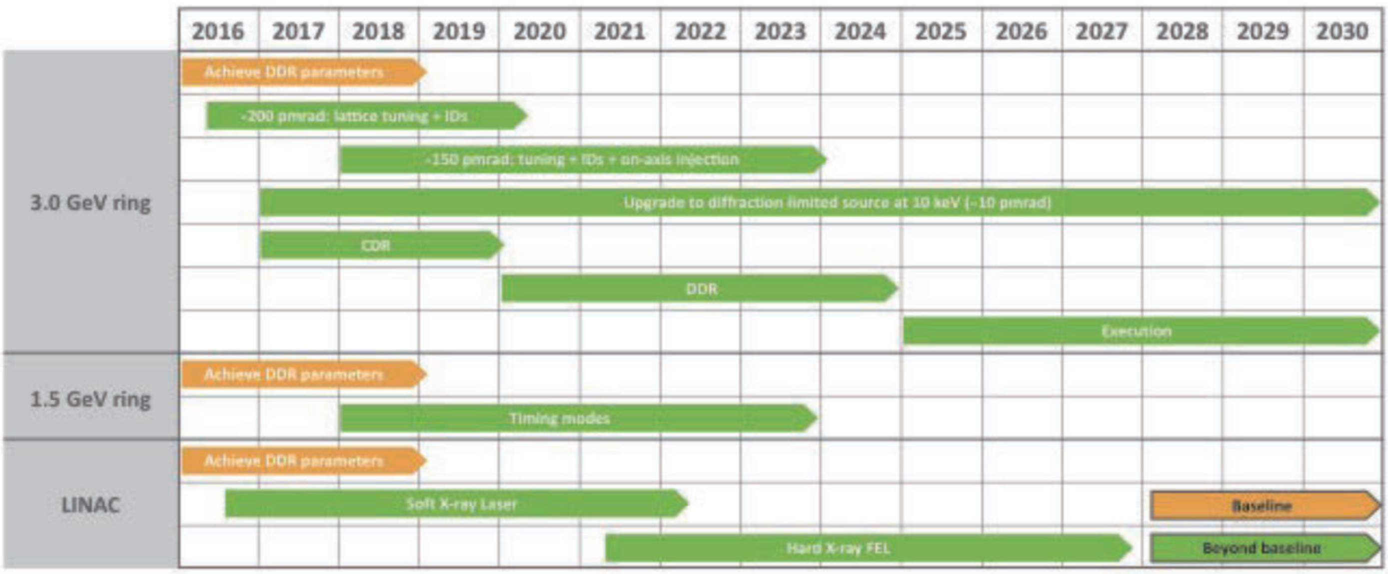
Accelerator development

For all three accelerators, achieving full baseline performance as well as establishing routine user operation with high reliability is first priority and will constitute the main task of the accelerator group over the next few years. The indicated time frame for all other projects (beyond baseline) is at this moment a rough estimate. They will require detailed planning and a definition of funding sources before any decision for execution can be taken.

Theoretical work on improving the emittance of the MAX IV 3 GeV storage ring is well under way. These studies have focused on increasing the transverse brightness by reducing the lattice emittance within the existing MBA lattice. This will be achieved by changing the magnet strengths only through changes of the excitation currents in their coils while keeping the magnets as they are. This work will be continued and is ultimately expected to lower the bare lattice emittance to the level of ~250 pm rad. At the same time, given the relatively low field (about 0.5 T) of the 3 GeV ring bending magnets, the addition of insertion devices (IDs) from new beamlines will provide a significant further reduction in emittance. In fact, combining the tighter optics with the enhanced damping from these IDs will bring the emittance down to the level of 200 pm rad.

While the development paths described hold the potential for significant brightness improvements, in the long run a more radical change will be required to maintain international competitiveness.

Preliminary design studies have explored a possible upgrade path in which a completely new machine replaces the MAX IV 3 GeV storage ring, while the existing tunnel and injector complex are kept unchanged. The number and length of long straights are also maintained, so that the already installed beamline hardware can to a significant extent still be used. However, a partial upgrade of the X-ray optics will probably be needed. The new storage ring should allow a 15–30-fold reduction in natural emittance compared to the current ring. This would result in a diffraction-limited light source up to hard X-ray wavelengths (~10 keV).



MAX IV Laboratory

Synchrotron Radiation for the Future of Humanity

Science for Society – Mankind faces many great challenges where the scientific community can help understand, explain and improve our world and the human condition. MAX IV can make contributions to directly address some of the societal challenges defined by the EU and UN, namely climate action, environment, resource efficiency and raw materials.

Environmental Science – This is an area where synchrotron techniques have already proven their ability to significantly contribute to progress within both fundamental and applied environmental science, from fundamental knowledge of phenomena and processes at the molecular level, to applied knowledge, such as development of strategies for the restoration and cleaning of contaminated areas.

Energy Materials – Direct conversion of solar energy into electricity is expected to be a major provider of electricity for the future. Nano-technology has shown great promise for producing very high efficiency photovoltaic devices, e.g. devices based on nano-wires. X-ray methods, in particular nanometre scale imaging with structural, chemical and electronic structure sensitivity, provide invaluable tools for characterising all aspects of such devices as well as for understanding and improving their synthesis.

Life Science – Despite huge technological and Nobel Prize-winning scientific advances, we still have a relatively poor understanding of many of the fundamental biological processes, interactions and in particular large and complex biological structures found in living organisms. This lack of detailed understanding definitely hampers many areas of biological science, from drug discovery, over implant design to palaeontology and evolutionary biology. However, synchrotron-based techniques can provide new fundamental insights across all areas of biology by providing superior quality images of supramolecular complexes, cells, tissues, and living organisms in three and four dimensions.

Novel materials – Finding novel material with specific properties not naturally available is a requirement for meeting many of the challenges our society is facing. Examples of such materials are light-weight, yet rigid fibre composites, polymers with controlled size and fraction of crystallinity, electronic materials for use in lighting devices or solar cells, and building materials combining ecological aspects with high mechanical stability. These materials and their processes must be studied *in-situ* with high spatial and chemical resolution. For this, X-ray methods are uniquely suited.

DESY: Deutsches Elektronen-Synchrotron

General Information

DESY is a national research center in Hamburg, Germany, focusing on research in accelerators, photon science, particle and astro particle physics. Researchers use the large-scale facilities at DESY to explore the micro- and nanocosmos in all their varieties – from the interactions of elementary particles and the properties of new types of nanomaterials to biomolecular processes that are essential to life.
The accelerators and detectors developed and built by DESY are unique research tools. The facilities generate extremely intense X-ray light over a large spectral range, accelerate particles to record energies and open completely new windows onto the universe.

DESY fact sheet

- A research center of the Helmholtz Association of German Research Centers
- A publicly funded national research center
- Employees: approximately 2300, including 650 scientists
- Guest scientists: > 3000 unique users for SR and FEL experiments from over 40 countries each year
- Training: more than 100 young people in commercial and technical professions
- Young scientists: more than 700 diploma students, PhD students and postdocs

PETRA III - Synchrotron radiation light source

PETRA III started user operation in 2010 and is one of the world's most brilliant storage ring based X-ray sources for high energy photons providing a brilliance exceeding 10^{21} ph/(s mm^2 mrad^2 0.1% BW). It operates at 6 GeV particle energy and provides a horizontal and vertical emittance of 1.3 nmrad x 0.01 nmrad, respectively, at photon energies between 250 eV and 200 keV depending on the beamline. PETRA III runs at 100 mA beam current in top-up mode and provides about 5000 h X-ray beam per year for user operations.

FLASH - Free-Electron Laser

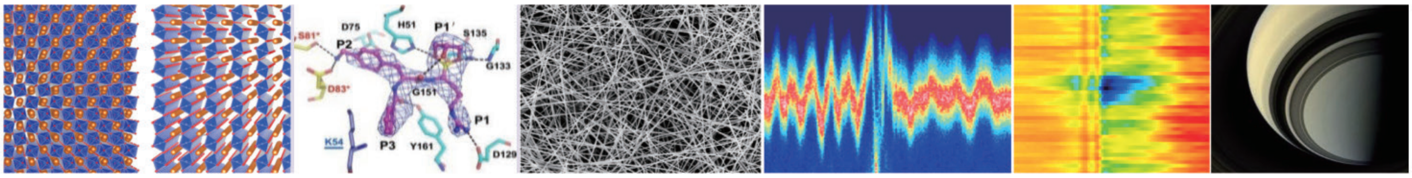
FLASH started user operation in 2005 as the first XUV and soft X-ray FEL. It is operated in the "self-amplified spontaneous emission" (SASE) mode with up to 8000 pulses/s and covers a wavelength range from 4 nm to about 90 nm in the first harmonics with GW peak power and pulse durations between 10 fs and 200 fs. The FLASH linac serves two FEL undulators in parallel. FLASH is available for user operations for about 4500 h per year.

***PETRA III*:**
3 experimental halls
24 beamlines and 1 under construct./com.

***FLASH*:**
2 experimental halls
2 parallel FELs
7 beamlines

DESY: Deutsches Elektronen-Synchrotron

Current Activities



PETRA III - Synchrotron Radiation Light Source

Probing the Earth's deep mantle in the lab

Simulating the conditions 2700 kilometres deep underground, scientists from different universities of France and Germany have studied an important transformation of the most abundant mineral on Earth, bridgmanite. The analysis at PETRA III can provide an explanation for a range of peculiar seismic observation.

Producing flexible circuits for 3D printing

A research cooperation between the Universität Hamburg and DESY has developed a process suitable for 3D printing that can be used to produce transparent and mechanically flexible electronic circuits. The electronics - a mesh of silver nanowires - that can be printed in suspension and embedded in various flexible and transparent polymers, was investigated at PETRA III.

Improving solar cells

Scientists from the Technical University of Munich have used the accurate X-ray vision provided by PETRA III to observe the degradation of plastic solar cells. Their studies suggest an approach for improving the manufacturing process to increase the long-term stability of such organic solar cells.

Facilitating the development of novel medications

An international team of scientists from Hamburg, Vienna and Amsterdam has come one step closer to understanding how tuberculosis bacteria infect human cells. This study reveals the molecular structure of a membrane channel that plays a key role in the infection.

FLASH - Free-Electron Laser

Probing near-field effects of the nanostructures

Scientists from Switzerland and Germany utilised the unique high-field THz radiation of FLASH to characterise the electric field, that was driving ultrafast processes at the solid state interfaces. This novel in situ approach using photon streaking paves the way for a polarisation-sensitive reconstruction of THz fields at dielectric interfaces.

Unraveling dynamic processes of atoms

Short-wavelength XUV light allows to access the innermost structure and dynamics of atoms. With the light from FLASH it is possible to decisively distort transitions of single and correlated pairs of electrons. The results also pave the road towards site-specific quantum control of molecular dynamics and chemical reactions.

Insights into the interaction of light and matter

An international team of researchers has been using FLASH to study the ultrafast, light-induced explosion of nanoparticles made up of xenon. Studying these clusters provides new insights into the fundamental interaction between extremely intense radiation and matter at ultra-short time scales.

Exploring astrophysics in the lab

Using FLASH, researchers took a sneak peek deeply into the lower atmospheric layers of giant gas planets such as Jupiter or Saturn. The observations reveal how liquid hydrogen becomes a plasma, and provide information on the materials' thermal conductivity etc. which are important data for planetary models.

DESY: Deutsches Elektronen-Synchrotron

Future Activities

PETRA IV - the ‘ultimate’ 3D process microscope

The PETRA IV project comprises the upgrade of the present synchrotron radiation source PETRA III into an ultra-low-emittance 4th generation storage ring:

- New multi-bend-achromat technology for the storage ring.
- Aiming for up to 100 times increase in brilliance as compared to PETRA III.
- First source to reach the fundamental physical limits for X-rays at 1 Å wavelength.
- An additional fourth experimental hall offering space for further new beamlines.
- Large qualitative step in synchrotron analytics.
- Ideal for in-situ 3D-microscopy on the nanometer scale.
- Conversion could be completed in 2026 at the earliest, depending on funding.

The investigation of chemical, physical and biological processes under in-situ and operando condition at the nano-scale is the main goal for PETRA IV.

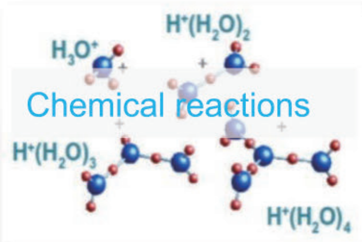
FLASH 2020+ – to study femtosecond dynamics at highest repetition rates

FLASH will be further developed as a high repetition rate free-electron laser:

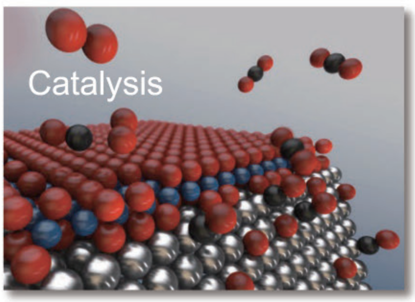
- Cover up to 6 decades of the electromagnetic spectrum (mm to nm) with coherent radiation for multi-colour experiments.
- Tunable gap undulators for both FLASH FELs for the establishment of novel FEL schemes.
- Laser to manipulate electron bunches in burst mode with 1 MHz repetition rate for defined spectral and timing properties.

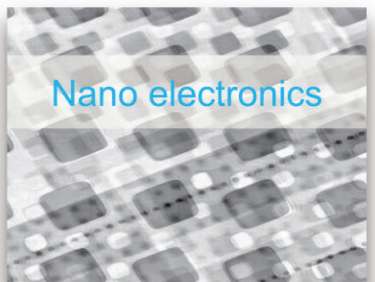
The agenda for FLASH 2020+ includes the investigation of very dilute samples, like gas phase reactions, atmospheric gas reactions and outer space chemistry and also ‚Quantum Molecular Movies‘ measurements of the dynamics of atoms and electrons for instance during catalytic reactions.

PETRA IV CDR (2019)



FLASH2020+ CDR (2020)





Synchrotron Radiation for the Future of Humanity

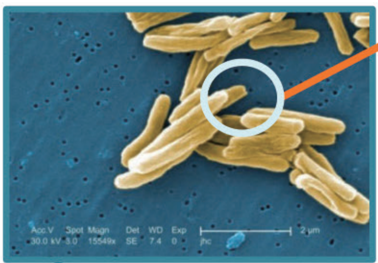
Future challenges

Nature is complex. The fundamental processes that determine everyday life, ranging from biological processes in living cells and light harvesting in photosynthesis to phase transformations in materials and friction in engines, encompass an enormous range of length scales, extending from atomic distances to macroscopic dimensions.

Global challenges in the fields of health, sustainable energy, transportation and information technology are intimately related to an understanding of these processes and the underlying fundamental interactions.

Missing links that connect properties on the nanoscale with those observed on macroscopic dimensions, prevent essential breakthroughs in these fields. The scale-bridging imaging of structures and their dynamics under in-vivo and working conditions is therefore indispensable to unravel emergent functionalities in nature. True progress in these fields will only be possible if the huge range of length scales can be explored simultaneously and in an interdisciplinary approach.

DESY aims to operate and build unique light sources to enable such groundbreaking studies in a multitude of disciplines.

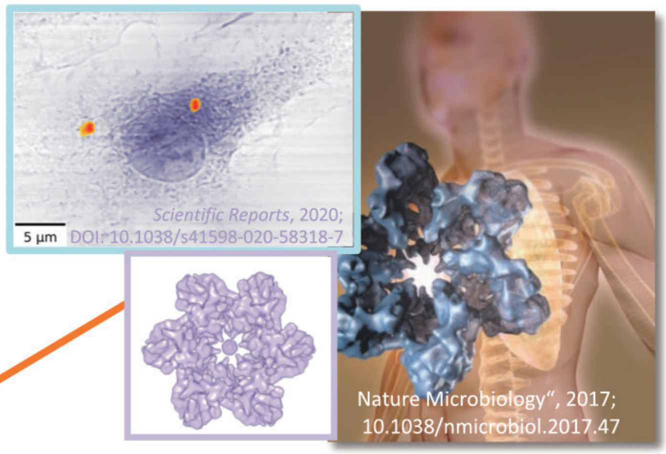


Example - challenge tuberculosis

As an example on how synchrotron radiation experiments can contribute to the future of humanity, we present studies on fighting the increasing resistance to drugs of the tuberculosis bacteria.

Tuberculosis resulted in 1.8 million deaths and 10.4 million new infections in 2015 (according to the WHO). Therefore, novel pharmaceuticals and treatments are urgently needed to lower these numbers.

The challenge here is to understand the complex biology of this bacterium and to find missing links on different scales between structures and their dynamics, in order to get the comprehensive information needed for the development of more efficient drugs.



Results obtained at PETRA III represent a big step forward in our understanding of the function of the secretion system of the pathogenic bacteria *Mycobacterium tuberculosis*.

In addition, further advanced scanning X-ray techniques at PETRA III were combined to trace iron nanocarriers for tuberculosis drugs within cells with very high precision. 3D-measurements will be possible in future and these techniques will benefit from an even brighter source - PETRA IV.

However, many molecular details of component, their function and suitable pharmaceuticals, not only of bacteria, are still largely unknown - future projects at DESY and partner institutes like CSSB and EMBL aim at closing this knowledge gap.

BESSY II

General Information

The BESSY II synchrotron radiation source at Helmholtz-Zentrum Berlin (HZB) is a third-generation 1.7 GeV storage ring dedicated to the photon energy range from VUV to soft X-rays. The source and the instrument suite are very versatile and provide photons at a high average brilliance. BESSY II features sophisticated fill patterns as well as manipulation and separation techniques of customized bunches to serve both time-resolved and photon hungry experiments at the same time. This capability, together with purpose-made insertion devices, allows for energy, spatial, temporal, and polarization control of the photon beam.

BESSY II is the European radiation standard and is used for metrology purposes by Germany's National Metrology Institute (PTB).

BESSY II serves an international user community spanning a great variety of disciplines. BESSY II is operated by HZB, whose scientists specialize in accelerator physics, energy materials research, and the development of new methods and instruments for science with photons.

The research at HZB provides the basis for strong scientific support for BESSY II users, ranging from special accelerator operation schemes to instrument and experiment design, the choice of sample environments and the specific instrumentation, to the evaluation and interpretation of results. In addition, lab infrastructure for energy materials research at HZB are available to BESSY II users for preparation of samples and additional characterization experiments.

BESSY II Facts & Figures

- Focus on soft X-rays, range THz to hard X-rays
- Flexible pulse & time structure, pulse length 1-20ps (slicing beamline ~ 100fs)
- Beamlines: 47 in operation, 38 in user operation (27 of these in use simultaneously)
- User from 32 countries (60% Germany, 30% EU, 10% World)

On average per year

- More than 1200 proposals
- About 800 beamtime campaigns
- More than 500 (verified) publications
- About 3200 user visits

The BESSY II storage ring with the Energy Materials In-Situ Laboratory (EMIL@BESSY II) for real time *(in-situ*) and at full functionality (*operando*) guided design, synthesis and analysis of energy materials, systems and devices. For details see *www.helmholtz-berlin.de/user/index_en.html*

Current Activities

As a multi-disciplinary multi-user facility, the range of the research portfolio at BESSY II includes physics (e.g., quantum physics in solids, superconductivity, magnetism, topological insulators, clusters, and disordered systems), chemistry (e.g., catalysis and artificial synthesis, real-time investigations of charge transfer), energy research (e.g., materials for energy conversion and storage, solar fuels, and battery research), biology (e.g., dental treatment, cells, and bacteria), medical and pharmaceutical research (e.g., bio and bio-mimetic materials, function mechanisms of drugs), materials testing, and cultural heritage investigations. Research at BESSY II addresses a set of grand challenges commonly faced by most developed societies, including health; a secure, clean, and efficient energy supply; smart, green, and integrated transport; resource efficiency; and limited raw materials.

HZB is currently paving the way for a **new dedicated soft to tender X-ray source – BESSY III –** to become operational by the end of the decade. Smart optimization and specialization of this facility will yield worldwide unique experimental capabilities, matching the need of HZB's research and attracting the brightest minds from all over the world. Based on the multi-bend achromat (MBA) technology, the new source will offer diffraction limited radiation over the soft and tender X-ray spectrum. A key aspect of the BESSY III facility will be highest stability, enabling nanometer spatially resolved experiments with unprecedented spectral resolution. BESSY III will access the relevant energy, length and time scales which define functionalities of novel materials; it will therefore serve as a "discovery machine" for material science, quantum materials, catalysis and energy research, physics, chemistry, and biology as well as metrology applications.

Personal exchange is the ultimate goal of the BESSY II User Meetings

SOLARIS

General Information

SOLARIS is a brand new fourth-generation synchrotron radiation source located at the National Synchrotron Radiation Centre in Kraków, Poland. It is the first research facility in Central and Eastern Europe to make such a big, multidisciplinary impact. The Centre operates under the auspices of Jagiellonian University. It was built between 2010 and 2015. The investment was co-financed with the European Union.

The SOLARIS storage ring is a replica of the 1.5 GeV storage ring designed and built concurrently at MAX IV Laboratory in Lund, Sweden. The 96m circumference ring is fed by 600 MeV electrons delivered by a 30 m S-band linac. The electrons are accelerated to a final energy of 1.5 GeV in the storage ring, which consists of 12 identical Double-Bend Achromat (DBA) cells. These DBAs are manufactured in accordance with the revolutionary design proposed by the MAX-lab accelerator team in Lund. All magnets of the DBA cell (dipoles, focusing sextupoles and quadrupoles) are integrated and machined in one solid block of iron. This innovative technology significantly simplifies the installation and alignment. Moreover, it allows for a very low emittance electron beam (6 nm·rad) in a machine with a relatively small size.

The DBA cells are separated by 3.5 m straight sections, of which ten are reserved for various insertion devices (ID). The twelfth section is fully equipped with two 100 MHz main cavities, providing an energy boost that compensates for the energy losses of the circulating electrons, and two passive Landau cavities for bunch elongation, improving beam life-time.

The SOLARIS synchrotron began user operations in 2018 with two beamlines (UARPES and PEEM/XAS). Since 2019 users can apply for access to Titan Krios G3i, the latest generation of a cryo-electron microscope. Six next experimental beamlines are under construction. Ultimately, the experimental hall of the Kraków accelerator will house up to 14 beamlines fitted with a total of around twenty experimental end-stations.

The SOLARIS storage ring parameters

Energy	1.5 GeV	Natural chromaticity ξ_x, ξ_y	-22.96, -17.4
Max. current	500 mA	Corrected chromaticity ξ_x, ξ_y	+1, +1
Circumference	96 m	Electron beam size (straight section centre) σ_x, σ_y	184 μm, 13 μm
Main RF frequency	99.91 MHz	Electron beam size (dipole centre) σ_x, σ_y	44 μm, 30 μm
Max. number of circulating bunches	32	Max. number of IDs	10
Horizontal emittance (without IDs)	6 nm rad	Momentum compaction	3.055×10^{-3}
Coupling	1%	Total lifetime of electrons	13 h
Tune Q_x, Q_y	11.22, 3.15		

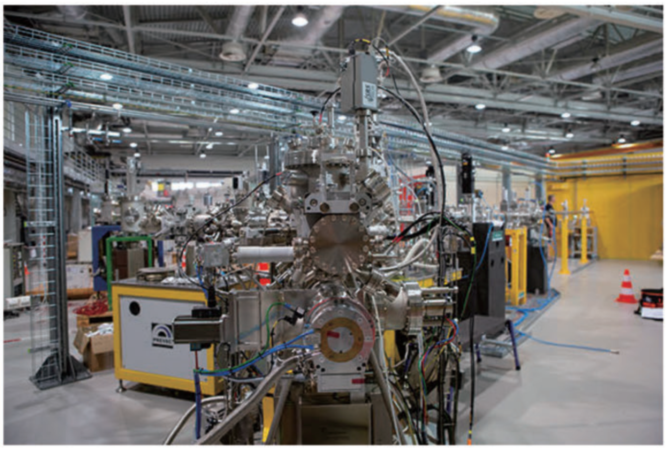
Current Activities

The SOLARIS Centre provides open access to its research infrastructure and constantly extends its measurement techniques offer. The main tasks of the SOLARIS team are to provide scientists from Poland and abroad with an outstanding, reliable research infrastructure and with substantive support during measurements.

Calls for proposals are organised twice a year, in spring and autumn. Between October 2018 and December 2019 SOLARIS users conducted 54 experiments in physics, materials engineering, and chemistry. Accepted proposals were submitted from 37 universities and research institutes, including 22 Polish and 15 foreign ones. In March 2020 scientists will begin regular measurements at the Cryo-EM laboratory offering access to the most advanced Titan Krios G4i microscope.

In the same time, next two beamlines have been being built in the SOLARIS experimental hall. At the beginning of the 2020 both beamlines entered the commissioning phase. First friendly users are planned to perform their measurements at PHELIX and a scanning transmission X-ray microscope in the end of 2020.

SOLARIS users



The PHELIX beamline

The SOLARIS team has been also conducting commissioning activities of the second diagnostic beamline. LUMOS, together with the first PINHOLE diagnostic beamline, will enable the SOLARIS synchrotron operators to correct beam instabilities, improving the quality of measurements carried out at the beamlines.

In addition, the SOLARIS team have began design and construction works on SOLCRYS, SOLABS (XAS-HN), SOLAIR and POLYX beamlines. At present, the most advanced are works on the SOLABS beamline. Plans are in place to have its construction completed and commissioning phase started by the end of 2020.

Finally, in the next few months the second cryo-EM microscope will be purchased and installed in the National Cryo-EM Centre at SOLARIS. The microscope will be open not only for scientific but also industrial research.

Future Activities

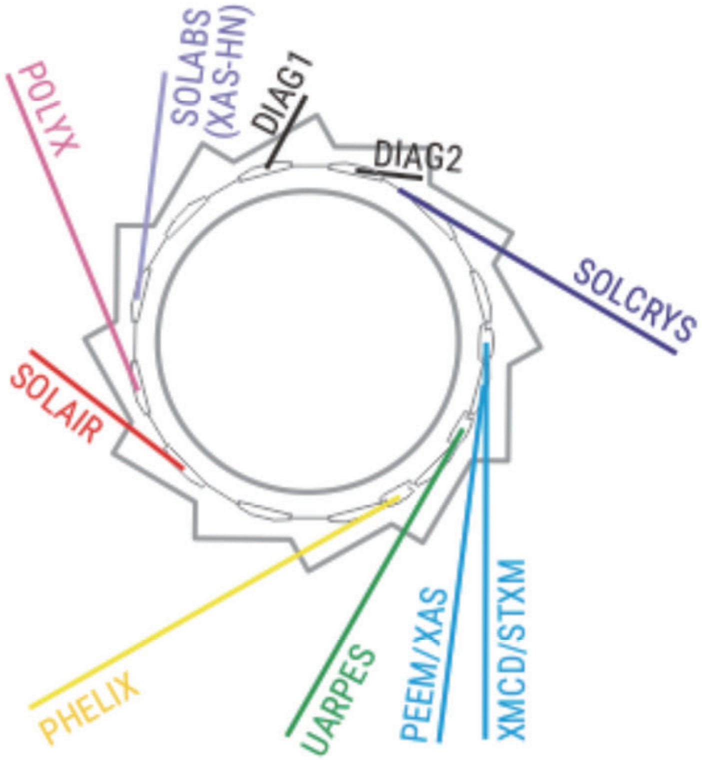
SOLARIS plans for the next few years include expansion of the experimental hall. Thanks to this, it will be possible to build the longest, most expensive and very much anticipated by the Polish scientific community a wiggler-based, high energy X-ray beamline for structural studies (SOLCRYS). The expansion of the hall will create space for the next four beamlines, as well as for auxiliary laboratories and offices for SOLARIS users and employees.

In the following years, in addition to the SOLCRYS beamline, SOLARIS will build and make available to scientists SOLAIR and POLYX beamlines. SOLAIR will enable chemical analyses at the micro-scale and intermolecular interaction studies in a wide range from far (FIR), through average (MIR) to close infrared (NIR). POLYX will enable multi-scale X-ray and multimodal imaging.

SOLARIS persistently collaborate with domestic and international research groups on the development of the next batch of the beamlines to achieve the full potential of the SOLARIS synchrotron.

Long-term development plans include expansion of the linear accelerator to provide full energy injection at 1.5 GeV enabling top-up mode of the operation. Such modernisation will allow the synchrotron to deliver constant intensity beam round the clock without any interruptions. Eventually, the quality of research will substantially improve.

Consecutively construction of an ultra-short X-ray pulse facility for studying fast transient processes is envisaged.



SOLARIS

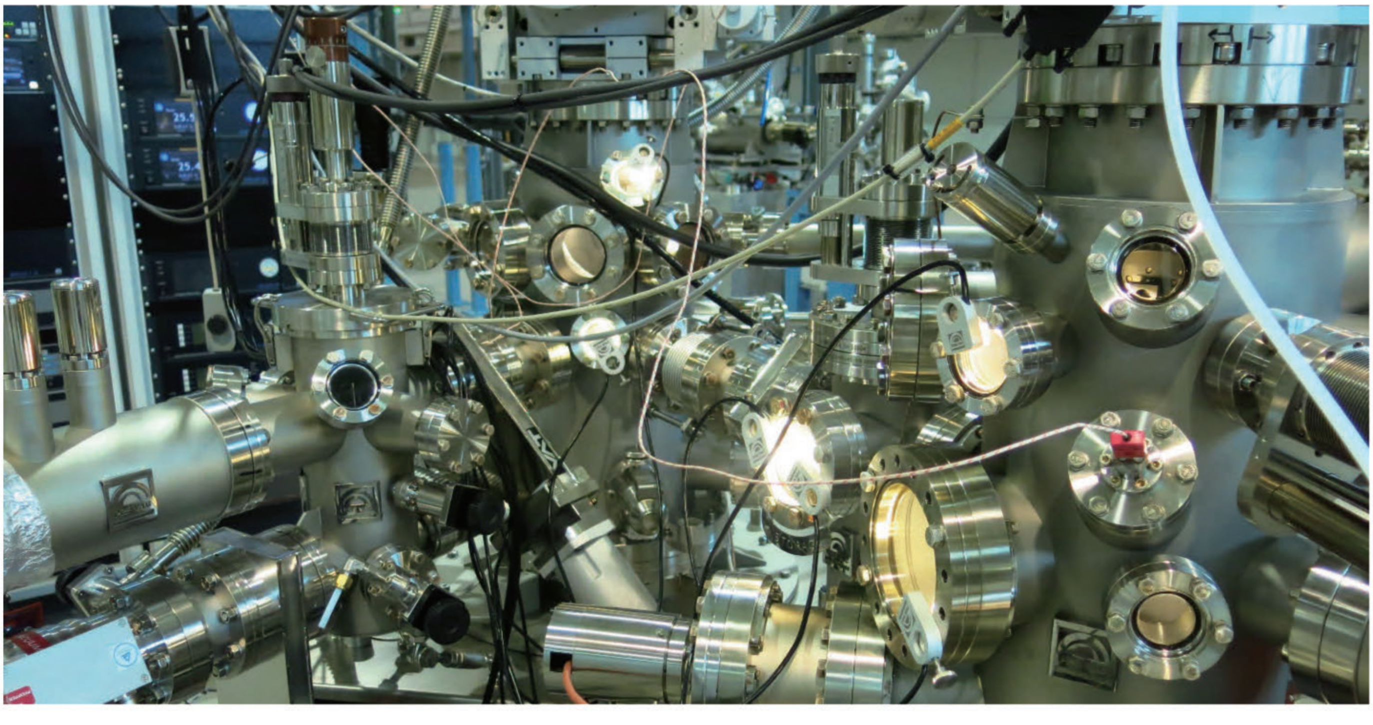
Synchrotron Radiation for the Future of Humanity

Synchrotron SOLARIS is the first research infrastructure of such a big size and potential to be built in this part of Europe. It is also one of the biggest, most modern infrastructure developments in Poland. The synchrotron is still expanding and upgrading to form a multi-user and multidisciplinary facility. It not only is creating opportunities for development for many research groups, but it will also enable easy access to Polish scientists, spurring great scientific potential and capabilities on a national level for Poland.

This scientific progress can serve as a catalyst for creating a proper foundation for industries, small and medium enterprises, and spin-offs oriented to R&D for the newest technologies. This type of research infrastructure is expected to attract companies to develop new technologies and processes and to enrich their expertise in many fields of technology, including control systems, data acquisition systems, detectors, and vacuum systems.

People often forget that the presence of big scientific infrastructure not only increases the knowledge and capabilities of scientists and engineers, but also raises awareness among people normally not involved in science. It of course enhances university-level education, but also sparks interest in science at primary and secondary school levels. It intrigues youngsters, inspiring them to seek a greater understanding of science and stimulating their curiosity.

For society it has another advantages. It of course creates new jobs for a wide range of employees. But what is more important, it demonstrates why society should invest in scientific technology – i.e., only when there are clear benefits obtained in all segments of the economy, from the local to the national level. SOLARIS is striving to deliver on these goals.



ELETTRA/FERMI

General Information

Elettra

In 1994, Elettra started user operations as Europe's first third-generation light source for soft X-rays.

At present, the Elettra storage ring in Trieste, Italy operates at 2.0 (75% of user time) and 2.4 GeV (25% of user time) with beam currents of 310 mA and 160 mA, respectively.

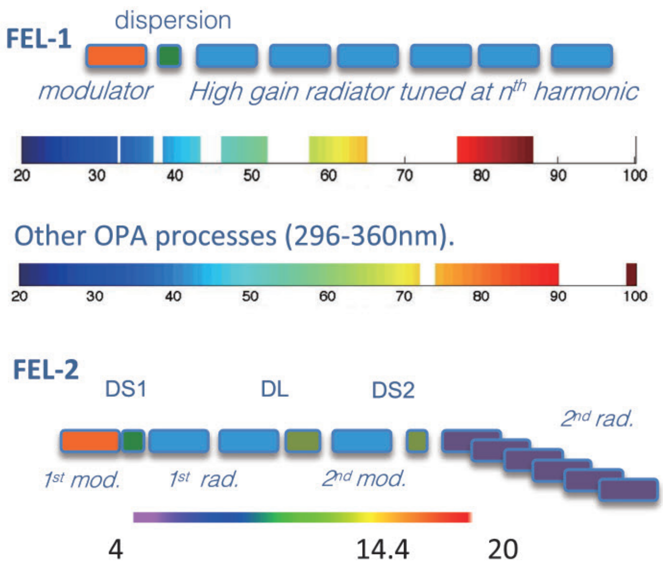
The total operating time is about 6400 hours/year of which >5000 are dedicated to users on a 24/7 basis.

The storage ring has a double-bend achromat lattice with an emittance of 7 nm-rad at 2 GeV and 10 nm-rad at 2.4 GeV. The ring features a twelve-fold symmetry with 12 long straight sections, of which 11 have insertion devices (IDs), including 3 wigglers (1 superconducting, 1 permanent magnet, and 1 electromagnetic elliptical) and 8 undulators (3 sections host Apple-II type). One other short undulator is installed in an additional 1.5 m short straight section in the arc. There are also 10 beam lines using radiation from 6 bending magnets. At present there are 27 operational beamlines open to users from academia and industry.

Since 2010, Elettra has operated in top-up mode, injecting 1 mA of current every 6 / 20 min at 2 GeV / 2.4 GeV, respectively.

FERMI

Elettra-Sincrotrone Trieste hosts FERMI, a fourth-generation light source that is a seeded Free Electron Laser (FEL) operating in the VUV to EUV and soft X-ray spectral range. The facility covers the VUV to soft X-ray photon energy range with two FELs (FEL-1 and FEL-2), both based on the High Gain Harmonic Generation (HGHG) seeded mode.



In FEL-1, the radiation resulting from conversion of the seed in the FEL up to the 13th to 15th harmonics is routinely delivered to user experiments in a spectral range of 100-20 nm. Higher orders can be attained with FEL-2, where the harmonic conversion is repeated twice (see Fig. 1). This scheme was implemented in FERMI FEL-2 for the first time and is used for the delivery to user experiments of seeded FEL coherent emission in the soft-X ray range (4-20 nm), up to harmonic orders of 65 and more (see Fig.2).

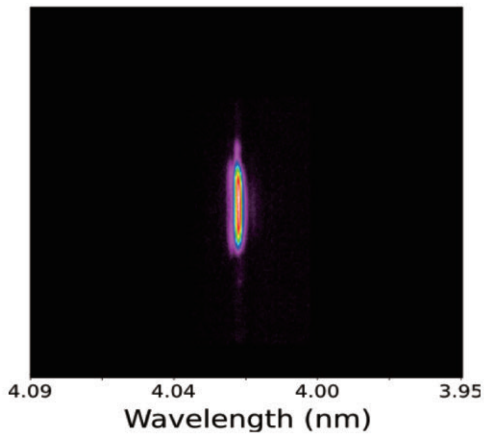


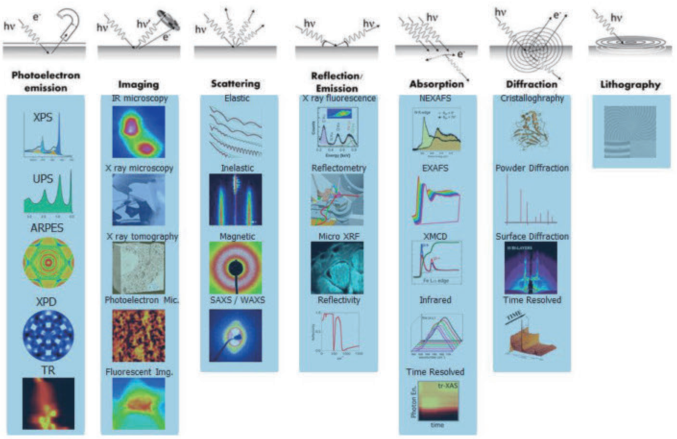
Fig. 2 - Spectral line of FERMI FEL-2 at harmonic 65

ELETTRA/FERMI

Current Activities

Elettra

Currently, 27 beamlines, including a storage ring free-electron laser, utilize the radiation generated by the Elettra source. All of the most important X-ray based techniques in the areas of spectroscopy, spectro-microscopy, diffraction, scattering, and lithography are present, together with facilities for infrared microscopy and spectroscopy, ultraviolet inelastic scattering, and band mapping. Versatile experimental stations are kept current with state-of-the-art technology, offering unique capabilities to carry out leading-edge research in diverse fields and disciplines.

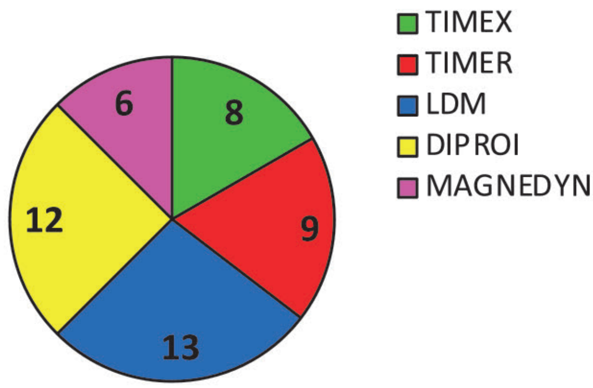


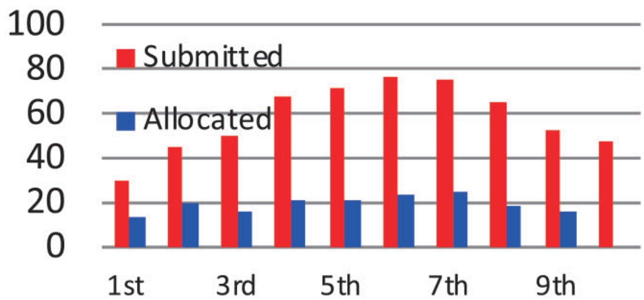
Elettra enables an international community of researchers from academy and industry to characterize structures and functions of matter with sensitivity to molecular and atomic levels, to pattern and nanofabricate new structures and devices, and to develop new processes. Every year, scientists and engineers from more than 50 different countries submit proposals to access and use time on 27 different beamlines. Because of its central location in Europe and its central role in the relevant science and technology networks, Elettra increasingly attracts users from Central and Eastern European, where the demand for synchrotron radiation continues to grow. Elettra also hosts the Statutory Seat of the Central European Research Infrastructure Consortium CERIC-ERIC. But Elettra's outreach is far larger and reaches many more countries around the world through longterm relations with the International Center for Theoretical Physics (ICTP) of UNESCO and the International Atomic Energy Agency (IAEA). In fact, access by researchers from developing countries as well as from India and Iran is constantly increasing. Elettra Sincrotrone Trieste has been the coordinator of the EU-supported networks involving synchrotron and free electron lasers in the European area, for the last decade.

FERMI

FEL-1 - High Gain Harmonic Generation (HGHG) 100-20 nm (and lower 17 nm are routinely used in experiments)
FEL-2 - Double stage HGHG with a fresh bunch injection technique 20-4 nm

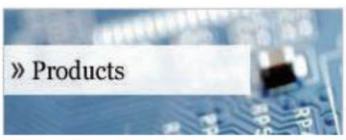
Operation with users since 2012 - Two calls for proposals per year since 2018.





10th call closed in 2019.
48 experiments proposed (50% on FEL-2) for the beamlines sharing the FERMI pulses. Other 20 proposals were received for the ancillary laboratories and the THz beamline working in parasitic mode.

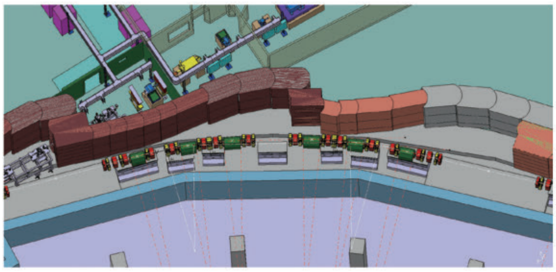
The Industrial Liaison Office (ILO) has been set up by Elettra-Sincrotrone Trieste S.C.p.A. to manage technology transfers and to promote the use of the center's facilities for applied research and for industrial applications.



Future Activities

Elettra 2.0

Although Elettra will continue serving the scientific community for many more years, we have designed the next generation facility, Electra 2.0, as a fully diffraction-limited ring.
The new accelerator will operate mainly at 2.4 GeV, replacing the current machine in the same tunnel. The lattice is a special symmetric 6-bend achromat (S6BA-E) with an emittance of 250 pm-rad and very small spot size and divergence (< 60 microns horizontal, <3 microns vertical, < 6 micro-rad). The photon source points from the insertion devices will remain at the same position as at present. For the dipole beam lines, various options are offered: either by short 2 T wigglers or by installing super-bends.
The project for Elettra 2.0 has received full funding approval from the Italian Finance Ministry for 170MEuro in 2017 with an estimated dark period (beam off/beam on) of 18 months. A conceptual design report is already available. The new machine will be diffraction-limited in the horizontal plane for $\lambda \geq 15$Å and in the vertical at 1% coupling for $\lambda \geq 0.15$Å, whereas its coherent fraction at 1keV will be 38%.

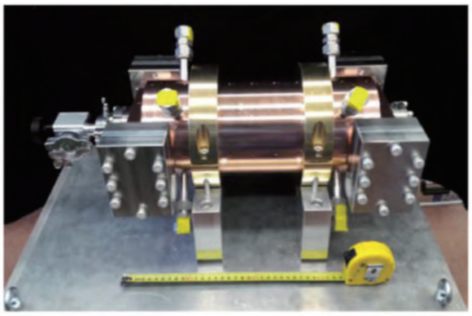


The improved source properties of Elettra 2.0 will push the performance of coherence- and photon-hungry techniques such as CDI, RIXS, XPCS, and all types of nano-spectroscopies. This, in turn, will lead to important advances in multi-length scale characterization of all types of matter with vastly improved spatial and temporal resolution.
As in most cases where the functional material properties are directly related to the dimensions, organization, and fluctuation dynamics of their building blocks, the advent of Elettra 2.0 will allow us to address major questions that remain open: (i) how can we select and precisely fabricate the desired nanoscale building blocks? (ii) what are the criteria for combining them into complex systems? (iii) how can we probe the role of the building blocks in the functionality of these systems in order to obtain the proper feedback for further development?
Making use of the state-of-the-art experimental techniques at Elettra 2.0 will help us move towards a full understanding of the mechanisms that control the behavior of complex systems. This progress, in turn, may lead to breakthroughs of crucial importance in materials science, chemistry and chemical engineering, energy, microelectronics, biomedicine, environmental science, and earth science.

FERMI

In 2018 the Echo Enabled Harmonic Generation (EEHG) experiment was conducted on FEL-2. EEHG is a seeded FEL scheme based on a double seeding scheme for the electron beam with external laser pulses. This entails significant advantages in terms of flexibility and robustness of operation. It has been possible to demonstrate that the EEHG scheme allows to laser with high gain and high quality up to 5.9 nm. Compared to the current scheme of FEL-2, EEHG demonstrates narrower and cleaner spectra and higher stability, from pulse to pulse, of the central wavelength. Furthermore, it has been possible to observe coherent emission (without FEL amplification) up to the harmonic 101 (2.6 nm), which is promising, with an optimized set-up, in order to study schemes that allow to generate the wavelength 2 nm, or beyond the oxygen K-edge, the final goal of the FERMI development plan.

In 2019 tests of the prototype of an innovative accelerating structure 0.5 m long (see figure) in the S band for the linac gave excellent results showing that the implementation of structures of this type throughout the final part of the linac will allow reaching electron bunches energy of 1.8 GeV. This is also crucial to reach the oxygen K-edge photon energies. In light of the results obtained, the construction of a 6-meter module which will replace one of the accelerating sections of similar length currently installed on the Linac is started and its installation is foreseen for summer 2021.

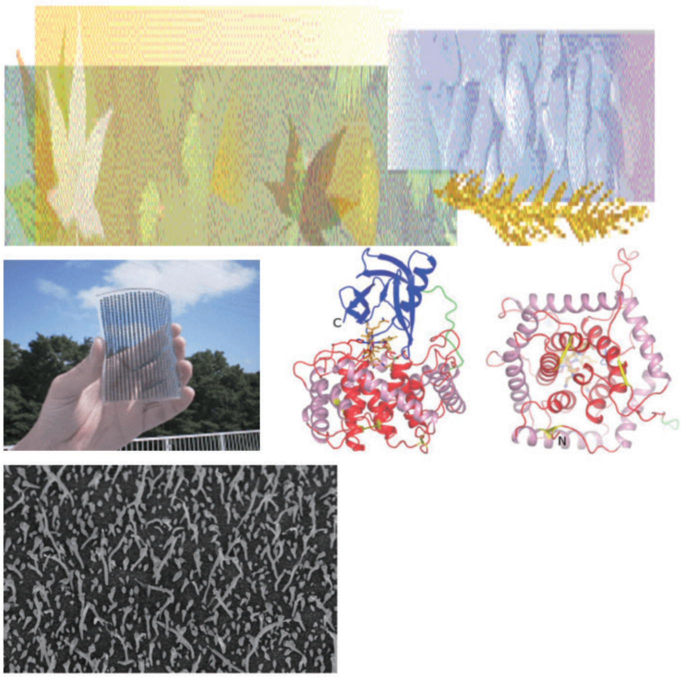


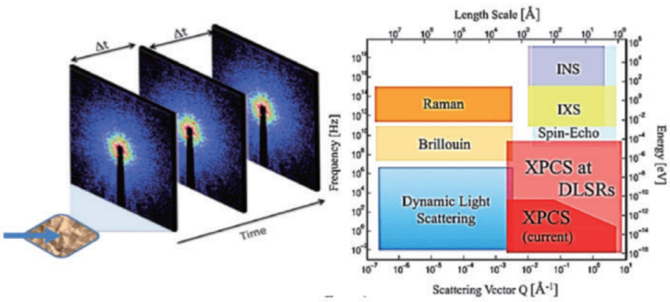
As part of the objective of reducing the duration of the FEL pulses generated by FERMI two actions were carried out. The first on the seed lasers that allowed a reduction of up to 30% of the duration of the FEL pulses signifying for FEL-1, below 30 fs at 20 nm, while for FEL-2 below 15 fs at 4 nm. At the same time a superradiance experiment was performed on FEL-2 which allowed to reach extremely short FEL pulse durations. This experiment is based on a multi-stage harmonic cascade seeding scheme, in which the part of the electron impulse participating in the FEL emission is increasingly shorter, thus also shortening the temporal amplitude of the generated FEL impulse. In the experiment on FEL-2, a three-stage radiator was configured in which the wavelength of the seed laser was first converted from 264 to 88 nm, then to 44 nm and then to the third harmonic at 14.67 nm; the duration of the impulse measured with autocorrelation techniques on the LDM experimental station was just 5 fs. Promising result that, after further tests also on FEL-1, it can also be made available to external users at a selected wavelength set.

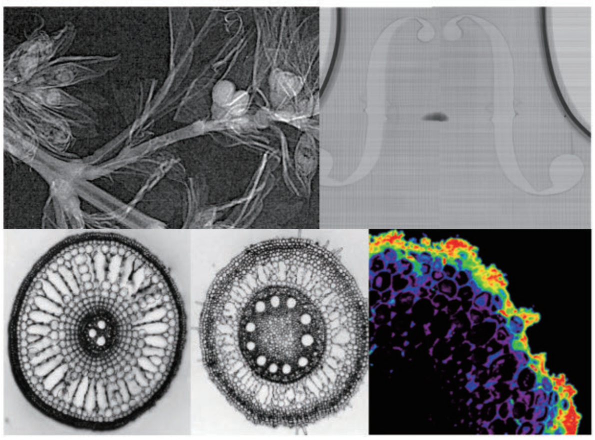
Synchrotron Radiation for the Future of Humanity

The great potential of synchrotron-based spectroscopy and microscopy methods in terms of structural, chemical, electronic, and magnetic sensitivity has long been recognized, but the imperfection of X-ray beams have imposed certain spectral, spatial, and temporal limits. As briefly discussed above, the photon flux parameters of Elettra 2.0 should overcome the current resolution-sensitivity limits for understanding interactions that control "'macroscopic" phenomena in functional materials as chemical reactions, phase transitions, events in biosystems, etc. Indeed, Elettra 2.0 will not be able to reach the femtosecond time resolution of FELs, but it will nonetheless enable users to follow the evolution of complex functional materials at their natural length scales, expanding time resolution down to the sub-nanosecond range.

Both CDI and ptychography will greatly benefit from the high brightness of Elettra 2.0 by reducing the acquisition time by a factor of 50. In particular, we expect real gains using resonant CDI and ptychography to access both chemical and magnetic information through absorption and scattering at atomic electron resonances. Consequently, we would be able to obtain scattering-imaging-speciation information with diffraction-limited lateral resolution.







The implementation of the Elettra 2.0 storage ring, including new beamlines and beamlines upgrades, will require substantial funding. However, the expanded spatial and temporal range of all photon-based techniques resulting from the availability of Elettra 2.0 will allow new classes of experiments in many disciplines, beneficial to science and technology to such an extent that the project will lead to significant positive social impacts.

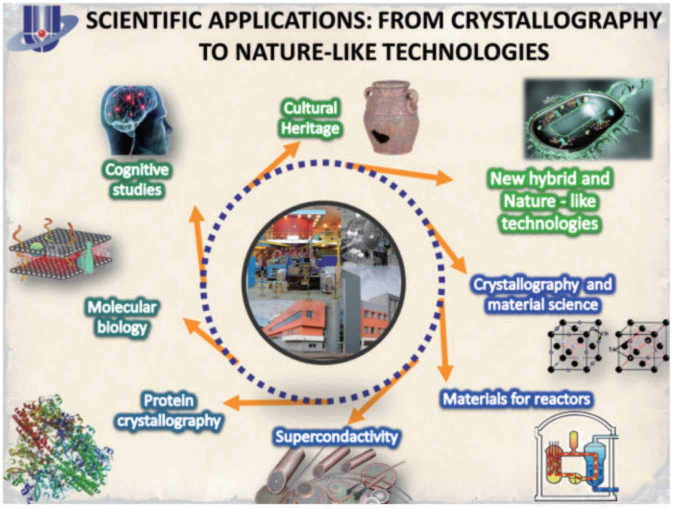
The coherent flux produced by Elettra 2.0 on a sample per square nanometer will be comparable with that from existing third-generation sources per square micrometer. Hence, X-ray spectroscopy experiments on individual meso/nano-sized constituents can be envisioned, even without the use of sophisticated focusing optics. In such experiments, using the most appropriate spectroscopic methods, information can be obtained about the local coordination environment of different types of atoms in such sub-units on the surface, at the interface, or in bulk, about the sizes and shapes of the individual mesoscopic units and about the overall structure. In addition, details about the interactions or real-time changes in the chemical state constituent units can be obtained.

Of great interest for both basic science and potential technological applications, strongly correlated systems include superconductors, topological insulators, 2D materials, artificial heterostructures, and magnetic systems, usually in the form of thin films and nanostructures. In these complex systems, electronic correlations should be explored at different energy, momentum, and length and time scales, while tuning external stimuli (e.g., temperature, pressure, and external fields) across their complicated phase diagrams. Many questions remain unanswered, for example: (i) the interplay between magnetism and superconductivity; (ii) competing phases of orbital, spin, and charge degrees of freedom; and (iii) spatial ordering phenomena.

Kurchatov Complex for Synchrotron and Neutron Research

General Information

Kurchatov Complex for Synchrotron and Neutron Investigations is among few places in the world where producing neutrons research reactor, synchrotron radiation facility, advanced X-ray laboratory instrumentation and supercomputer mega-class research complex for modeling and data processing are collected at the same site. This unique combination of capabilities helps to achieve a brand new quality of fundamental and applied research. Mega-science facilities of Kurchatov Complex constitute the basis for the development of principally new type of scientific investigations based upon the convergence of nano-, bio-, information, cognitive and socio-humanitarian (NBICS) sciences and nature-like technologies.



Kurchatov Synchrotron Radiation Source (KSRS)

User operations: started from 1999

2.5 GeV, 150 mA decay mode of operation

3384 h of operation with 3035 h user time in 2018Y

~600 visiting users in 2018Y from 51 Russian and 6 foreign organizations

241 proposals submitted, 219 approved (90.9 %) in 2018Y

User affiliation: 48% of beamtime was given to Russian Academy of Sciences, 27% - university users, 23% internal Kurchatov institute users, 2% - users from abroad in 2018Y

~150 publications/year in refereed journals.

Research Reactor IR-8

User operations: started from 1981

Thermal power: 6 MW

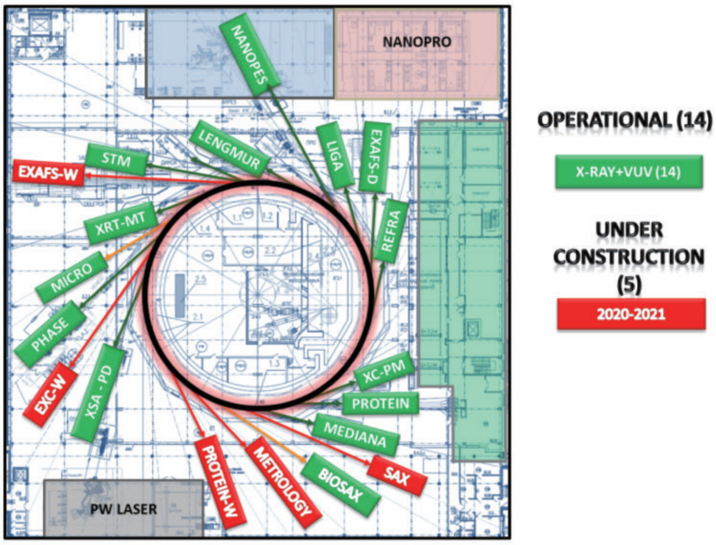
Neutron flux at horizontal channels: 10^{10} $n \cdot cm^{-2} \cdot s^{-1}$

2624 h of operations with 2300 h user time, in 2018Y

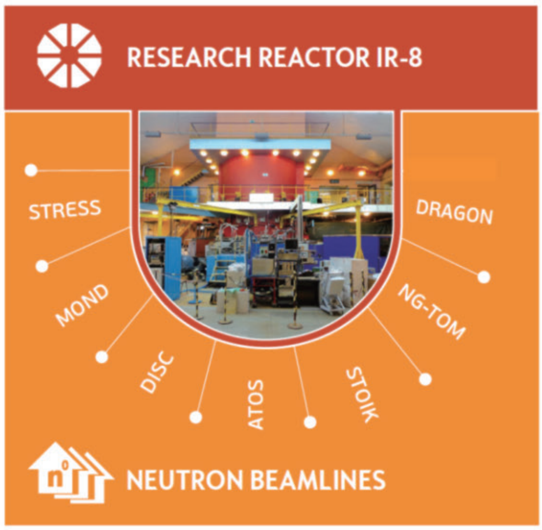
13 organizations used horizontal beamlines in 2018Y

63% of beamtime was given to external users,

37% was used for in-house research



KSRS scheme
14 beamlines are in operation.
5 await for construction.



IR-8 scheme
7 beamlines are in operation.
3 await for construction.

Kurchatov Complex for Synchrotron and Neutron Research

Current Activities

Kurchatov Synchrotron Radiation Source (KSRS)

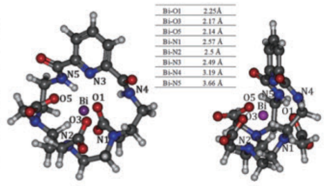
Kurchatov Synchrotron Radiation Source is the only dedicated synchrotron facility in Russian Federation. It serves to nearly all institutes working on study of structure of matter.

Distribution of users-2018. The bigger circle means more users came from this city.

Building of Kurchatov Synchrotron Radiation Source

New Drug Design

Bismuth complexes are prospective drugs for targeted alpha therapy. The conformation of complexes in solutions was studied at "Structural materials science“ beamline.



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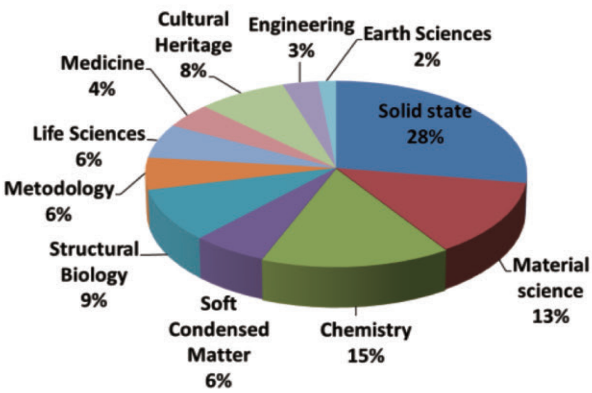
The research activity of synchrotron radiation users is aimed to:

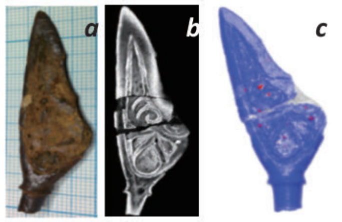
- nanodiagnostics of ordered organic and bioorganic structures using highly precise spectrally selective X-ray techniques;
- study of the organic structures and processes in biological objects for genetic engineering, biotechnology, new drugs design;
- structural diagnostic for ordered nanosystems and multilayer heterocompositions study;
- study of poly- and single crystals, metal alloys, biological macromolecules solutions; powder diffractometry; X-ray fluorescence elemental analysis;
- convergent visualization for cultural heritage study;
- X-ray absorption spectroscopy (EXAFS/XANES) methods development;
- new medical diagnostics methods development;
- combined applications of complementary synchrotron-neutron research;



KSRS areas of research

Studying Cultural Heritage

Researchers of Kurchatov synchrotron together with national museums uncover hidden history. Severely corroded arrow heads showed their decoration.

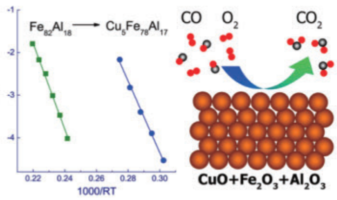


Arrow head. Optical Image; X-ray image; 3D reconstruction

E.S Kovalenko et al./ 7Th ECNS Conference (2019) 74

Controlling Catalysis

Catalysts for the oxidation of carbon monoxide. In-situ EXAFS at the station "Structural materialization" allowed to determine the mechanism of growth of catalytic activity of catalysts with the addition of copper.



A. V. Fedorov et al. / Catalysis Letters 148 (2018) 3715-3722

Research Reactor IR-8

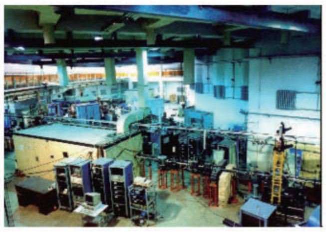
The neutron research complex based on the IR-8 research reactor is used to carry out fundamental and applied research in the fields of nuclear physics, solid state physics, radiation materials science, nanostructures physics, radiobiology and biophysics, since it allows complex studies using neutrons and gamma radiation in a wide range of wavelengths using various techniques.

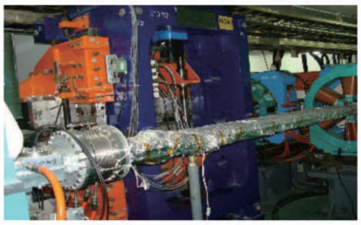
BEPC/BSRF & HEPS

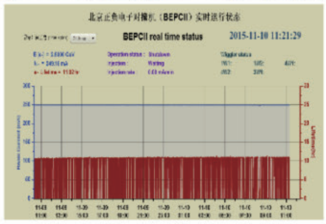
General Information

The Beijing Electron Positron Collider (BEPC) was constructed in 1980s and upgraded to be BEPCII as a Tau-Charm factory machine from 2004 to 2009, with a designed luminosity of $1\times10^{33}cm^{-2}s^{-1}$ at the beam energy of 1.89GeV. The BEPCII contains a linac, two transport lines and three storage rings. Among them, two rings are in parallel for e- and e+ beams, respectively. One machine with two purposes is the most important feature of the BEPCII, which means to provide beam not only for high energy physics, but for synchrotron radiation users in the dedicated time or parasitical operation. The two halves of the outer rings are connected as the third ring with 14 beam lines from 5 wigglers and 9 dipole magnets. This facility based on the BEPC is called BSRF.

BSRF was the first synchrotron radiation facility in China, and now it is the most important experimental platform in northern China. "Despite its limitations, the BSRF experimental station completed in 2002 has provided an excellent platform for structural genomics research.", Z. Rao, "History of protein crystallography in China", Phil. Trans. R. Soc. B (2007) 362, 1035–1042.

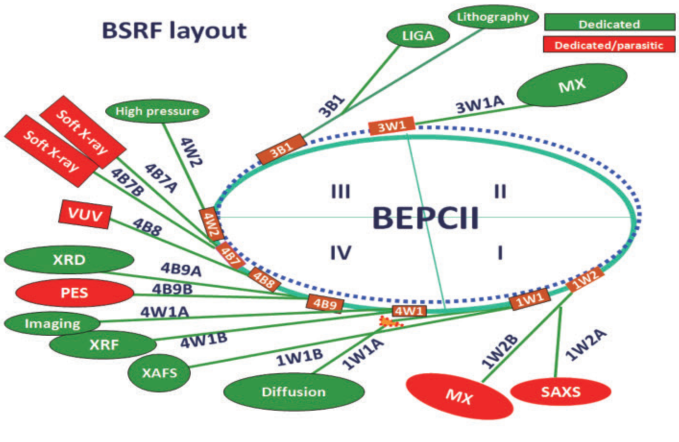






Beam lines extracted from 5 wigglers, 4 bending magnets
14 beamlines & 15 end-stations in total
Dedicated SR mode: 2.5GeV, 250mA
Parasitic SR mode: depending on HEP

User operation started from 1989 (BEPC) and 2007 (BEPCII). Top-up injection from 2015
Dedicated beam time: ~2000 hrs/year
Parasitic beam time: ~ 5000 hrs/year
Proposals: ~550/year
Users: ~1800/year
Papers: ~170/year

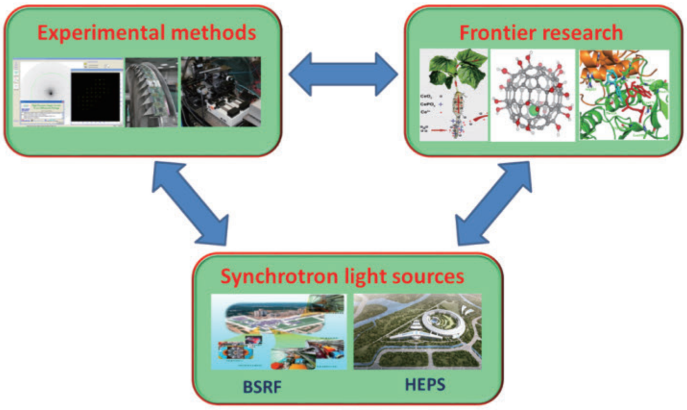


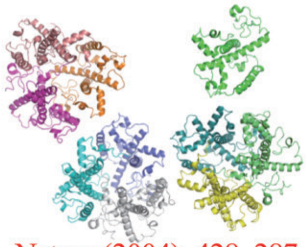
With the development of economy and science in China, more and more users appeal a new light source, even after the operation of the Shanghai Synchrotron Radiation Facility, which started in 2009. A large number of users at the area of Beijing and its nearby places, requests a high energy photon source (HEPS) for the multidisciplinary research in northern part of China.

A beam energy of 6 GeV & ultra-low emittance ring-based synchrotron radiation light source, proposed in 2008, was shortlisted in the large scientific infrastructure project in the 13th five-year plan of China in 2016.

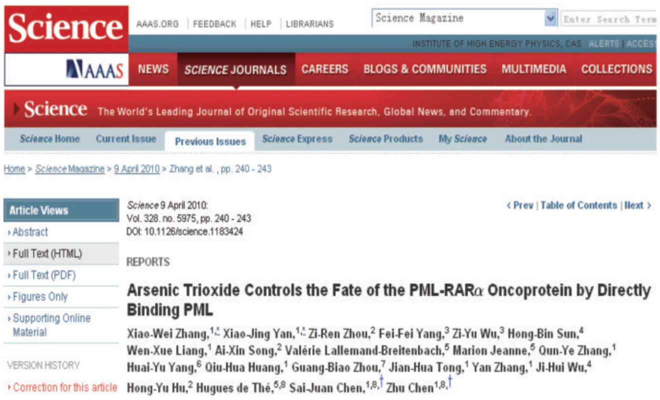
Current Activities of BSRF

BSRF was recognized as a 1st generation light source, based on the design of e^+–e^- collider, with the parasitic beam time and the dedicated operation mode. As an important platform of multidisciplinary research in some crossed scopes of solid state physics, material science, life science, source & environment, and micro-electronic technology, it can provide synchrotron radiation light with a wide wave band from X-ray to vacuum ultra-violet.





Nature (2004), 428, 287
Dr. Wenrui Chang, IBP
The first X-ray structure of LHC-II in icosahedral proteoliposome assembly at atomic detail.


Science The World's Leading Journal of Original Scientific Research, Global News, and Commentary.

Science 9 April 2010:
Vol. 328. no. 5975, pp. 240 - 243
DOI: 10.1126/science.1183424

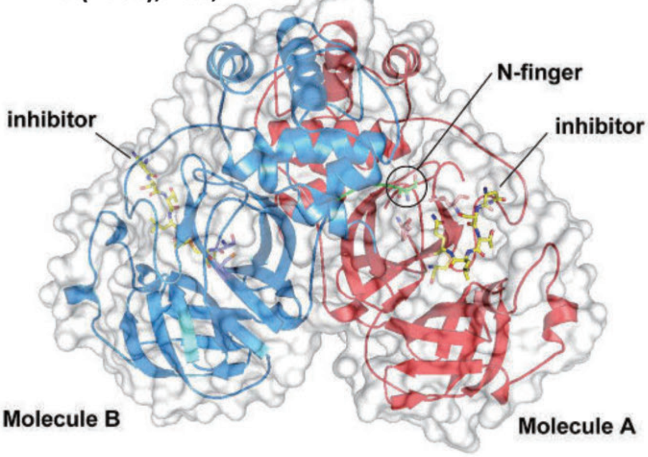
REPORTS

Arsenic Trioxide Controls the Fate of the PML-RARα Oncoprotein by Directly Binding PML

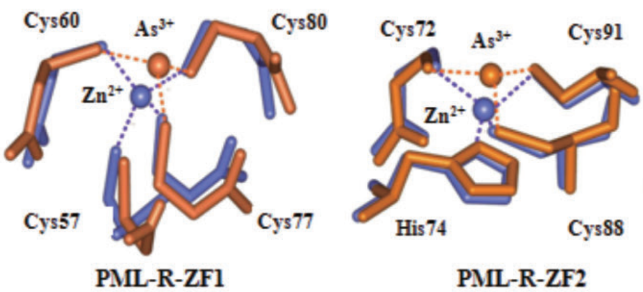
Xiao-Wei Zhang,[1,*] Xiao-Jing Yan,[1,*] Zi-Ren Zhou,[2] Fei-Fei Yang,[3] Zi-Yu Wu,[3] Hong-Bin Sun,[4] Wen-Xue Liang,[1] Ai-Xin Song,[2] Valérie Lallemand-Breitenbach,[5] Marion Jeanne,[5] Qun-Ye Zhang,[1] Huai-Yu Yang,[6] Qiu-Hua Huang,[1] Guang-Biao Zhou,[7] Jian-Hua Tong,[1] Yan Zhang,[1] Ji-Hui Wu,[4] Hong-Yu Hu,[2] Hugues de Thé,[5,8] Sai-Juan Chen,[1,8,†] Zhu Chen[1,8,†]

BSRF research highlights

PNAS (2003), 100, 13190



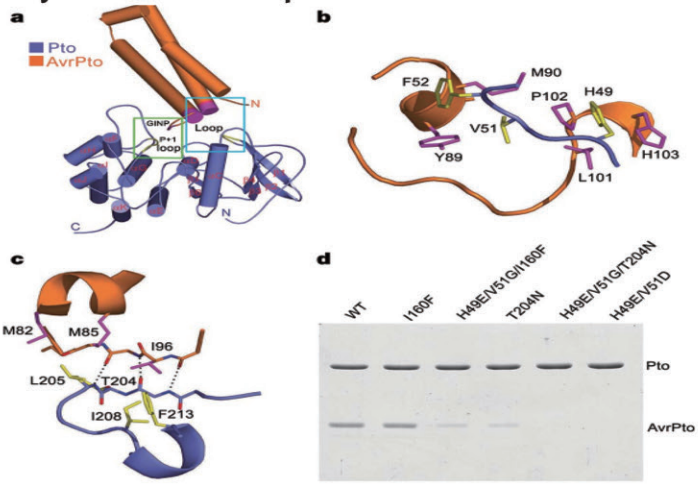
Prof. Zihe Rao, Institute of Biophysics
The SARS main protease and the complex with inhibitor. Several lead compounds have been found based on the structures. A SARS medicine has then been finished all the pre-clinic tests, waiting for clinic trials.



Science (2010), 328, 240
Dr. Zhu Chen, Shanghai Institute of Hematology
The XAFS results show that arsenic binds directly to cysteine residues in zinc fingers located within the RBCC domain of PML-RARa and PML, resulting in enhanced SUMOylation and degradation, and therefore apoptosis of cancer cells.

Current Activities of BSRF

The structural basis for activation of plant immunity by bacterial effector protein AvrPto

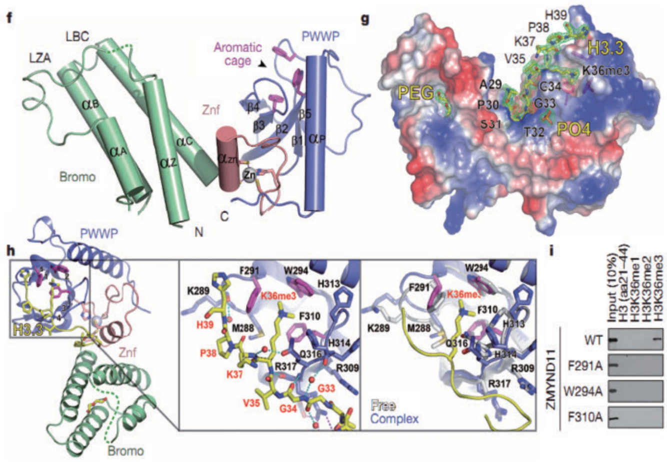


NATURE (2007), 449, 243

Dr. Jijie Chai, NIBS

The complex of the tomato protein kinase Pto and the *Pseudomonas syringae* effector protein AvrPto. The structure depicts the mechanism of how plant trigger disease resistance and programmed cell death.

ZMYND11 links histone H3.3K36me3 to transcription elongation and tumour suppression

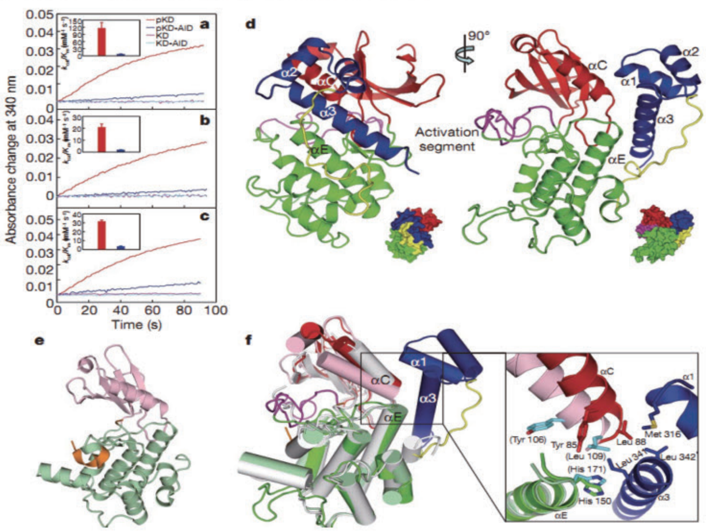


NATURE (2014)

Prof. Haitao Li, Tsinghua University

The candidate tumour suppressor ZMYND11 Specifically recognizesH3K36me3 onH3.3 (H3.3K36me3) and regulates RNA polymerase II elongation.

Structural insight into the autoinhibition mechanism of AMP-activated protein kinase



NATURE (2009), 459, 1146

Prof. Jiawei Wu, Tsinghua University

The structure of AMP-activated protein kinase (AMPK) in various status, showing the primary mechanism of AMPK autoinhibition and suggest a conformational switch model for AMPK activation by AMP.

Homogeneously dispersed multimetal oxygen-evolving catalysts

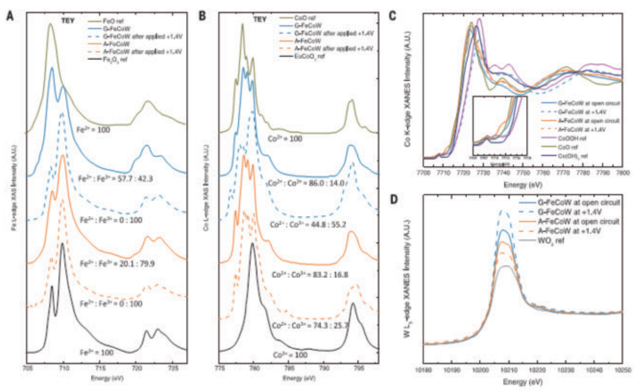


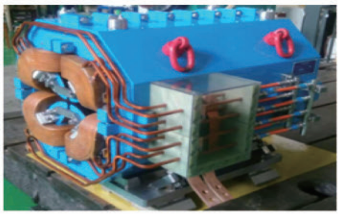
Fig. 3. Surface and bulk x-ray absorption spectra of G-FeCoW oxyhydroxide catalysts and A-FeCoW controls. (**A**) Surface-sensitive TEY XAS scans at the Fe L-edge before and after OER at +1.4 V (versus RHE), with the corresponding molar ratio of Fe^{2+} and Fe^{3+} species. (**B**) Surface-sensitive TEY XAS scans at the Co L-edge before and after OER at +1.4 V (versus RHE). (**C**) Bulk Co K-edge XANES spectra before and after OER at +1.4 V (versus RHE). (Inset) The zoomed in pre-edge profiles. The Co K-edge data of $Co(OH)_2$ and CoOOH are from (*30*). (**D**) Bulk W L3-edge XANES spectra before and after OER at +1.4 V (versus RHE).

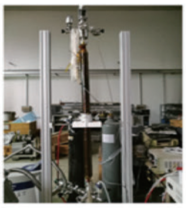
Fe, Co and W gelled oxyhydroxides materials with an atomically homogeneous metal distribution. X-ray absorption and computational studies reveal a synergistic interplay between tungsten, iron, and cobalt in producing a favorable local coordination environment and electronic structure that enhance the energetics for OER (oxygen-evolution reaction)

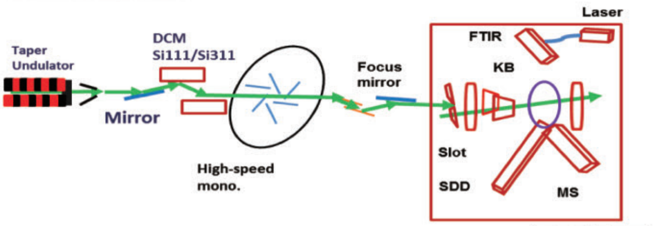
Future project of synchrotron light source, HEPS

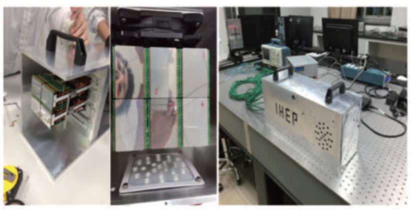
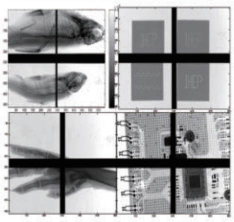
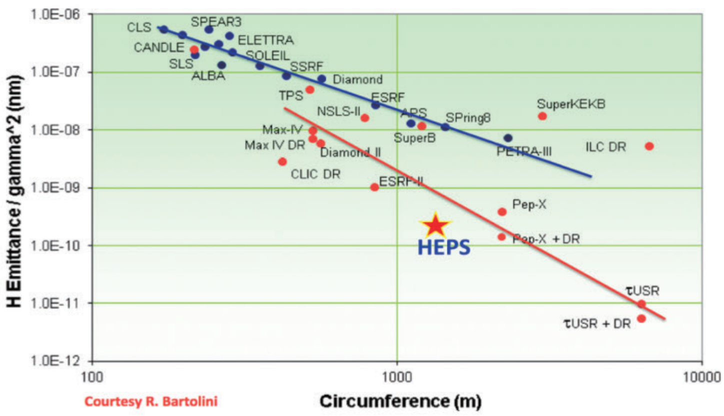
The R&D project of HEPS, HEPS-TF, had been carried out since April, 2016. Aiming at the quasi-diffraction limited storage ring based light source, the HEPS-TF takes 3 years to try to develop some key technologies of the diffraction limited storage ring, such as high gradient quadrupole, longitudinal gradient dipole, NEG coating of vacuum chamber, high precision girder for magnets, high resolution and accuracy power supply for magnets, low temperature undulator and superconducting wiggler, high stability environmental control, and K-B mirror for fine measurement of beam profile. In the meantime, some key technologies for the beamlines and stations of high energy X-ray diffraction, CDI and XPC, NRS and IXS, nano-probe, time-resolution of 10 ps to ms, hard X-ray imaging, protein crystallography, XAFS, in situ surface diffraction and scattering, high throughput SAXS, etc., and some for engineering materials. The whole project of HEPS-TF was finished in late Oct., 2018.

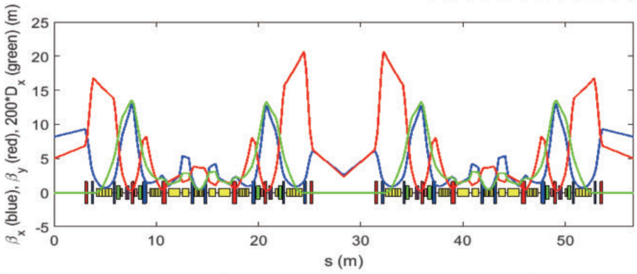
One of the main tasks of HEPS-TF is the accelerator physics design for the HEPS main ring and its injector. Following the pioneer of DLSR machine, MAX IV, the MBA lattice was chosen for the HEPS storage ring design, with a horizontal natural emittance as small as 34 pm·rad with anti-bend at the beam energy of 6 GeV. 14 beamlines were chosen to be constructed in the Phase I of the HEPS.









Main parameters	Unit	Value
Beam energy	GeV	6
Circumference	m	1360.4
Emittance	pm·rad	< 60
Brightness	phs/s/mm^2/mrad^2/0.1%BW	>10^{22}
Beam current	mA	200
Injection		Top-up

Time schedule of HEPS construction:

2017 – CD0 & CD1 proposed & approved
2018 – CD2 & CD3 proposed & approved
June 29, 2018 – construction started
2024 – commissioning starts
Dec. 2025 – project completed.

SHANGHAI SYNCHROTRON RADIATION FACILITY

General Information

Accelerators

* Linac Energy: 150 MeV
* Booster: 150 MeV-3.5 GeV
* Storage Ring Energy: 3.5GeV,
* Circumference: 432 m
* Emittance: 3.9 nm·rad
* Beam current: 260 mA/top-up
* Straight sections number: 20

Current beamlines

* Macromolecular crystallography
* High resolution X-ray diffraction
* X-ray absorption fine structure spectroscopy
* Hard X-ray micro-focusing
* X-ray imaging and biomedical application
* Small angle X-ray scattering
* Soft X-ray spectromicroscopy
* Protein micro-crystallography
* Protein complex crystallography
* High throughput crystallography
* Bio small angle X-ray scattering
* IR time-resolved/micro spectroscopy
* Dreamline: APRES & PEEM
* Soft x-ray ARPES
* Soft X-ray AP-XPS/PIPOS

Overview

The Shanghai Synchrotron Radiation Facility (SSRF), a 3.5 GeV third generation light source, is the largest scientific user facility ever built in China. Located at Shanghai Zhangjiang High-Tech Park, currently the SSRF consists of a 150 MeV electron linac, a full energy booster, a 3.5 GeV storage ring, and 15 operational beamlines. A total of 16 new beamlines with 32 experimental stations are under construction.

Since its user operation started in May 2009, SSRF has devoted to the development of up-to-date experimental methods, in-situ sample environments and key techniques, which continuously support the promotion of facility productivity and expansion of research frontiers. Up to now, SSRF has served for over 26 thousands users from about 2800 research groups affiliated with 549 institutes, universities, hospitals and high-tech companies all over the country.

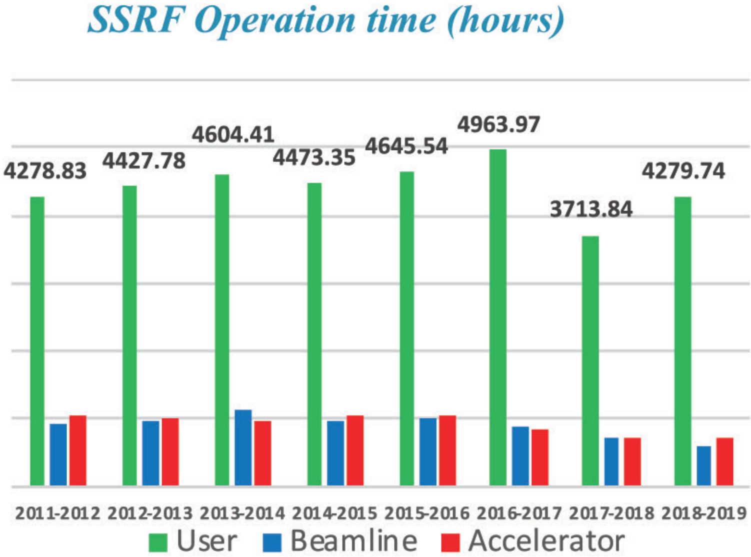
The 15 operational beamlines of SSRF have supported a large number of user experiments and promoted a rapid development of science and technology in many disciplines in China, particularly in structural biology, condensed matter physics and materials science, chemical science, energy science, environmental science, biomedical and pharmaceutical science, as well as the industrial applications.

SHANGHAI SYNCHROTRON RADIATION FACILITY

Operation status

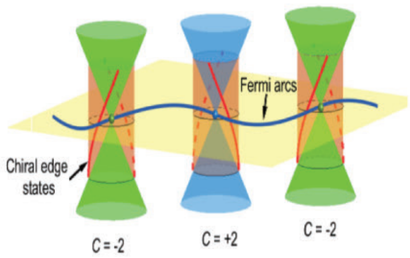
The SSRF accelerator complex has reliably operated since its dedication. The availability and MBTF are improved year by year and reached 98.6% and 81.13 hours respectively in 2014. The longest non-trip operation time is 307 hours.

Top-up operation for user experiments at SSRF commenced in December, 2012. The storage ring beam is routinely operated at 260±0.5 mA. The sub-micron storage ring orbit stability in both vertical and horizontal planes has been achieved based on slow and fast orbit feedbacks.

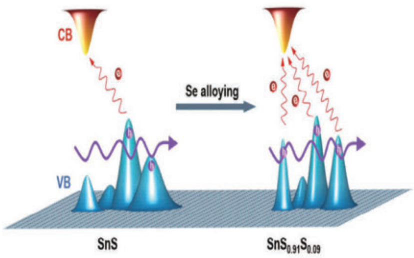


Current activities

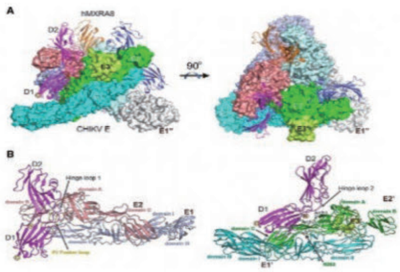
During ten years of operation, SSRF extensively supported the scientific research and the industrial R&D, which led fruitful outcomes with about 6000 publications, including more than 100 were published on Science, Nature and Cell. Plenty of important breakthroughs were made in fields of condensed matter physics, life science and materials science, etc., such as the experimental discovery of the unconventional chiral Fermion in CoSi, the revealing for the mechanism of interaction between arthritis alpha virus CHIKV and MXRA8 receptor, and the invention of the high thermoelectric performance in low-cost $SnS_{0.91}Se_{0.09}$. Besides, SSRF also was intensively devoted to promote industrialization, like helping for developing the FDA approved Chinese anticancer drugs Brukinsa, for building the first mass production spinning grade single-layer graphene oxide, for producing high-performance copper alloys used for the contact wire in Chinese high-speed railway and so on.



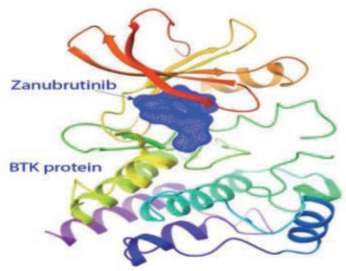
H Ding group, ***Nature*** 2019.



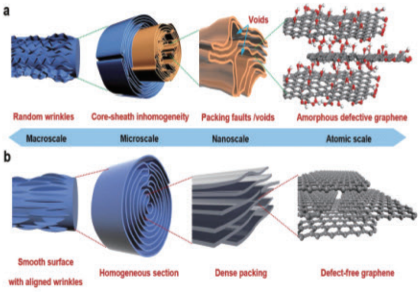
L Zhao group, ***Science*** 2019



F Gao group, ***Cell*** 2019



FDA approved anticancer drug Brukinsa



First mass production for single-layer graphene oxide

High-performance Cu alloy used for contact wire for high-speed train

SSRF Phase-II Beamline Project

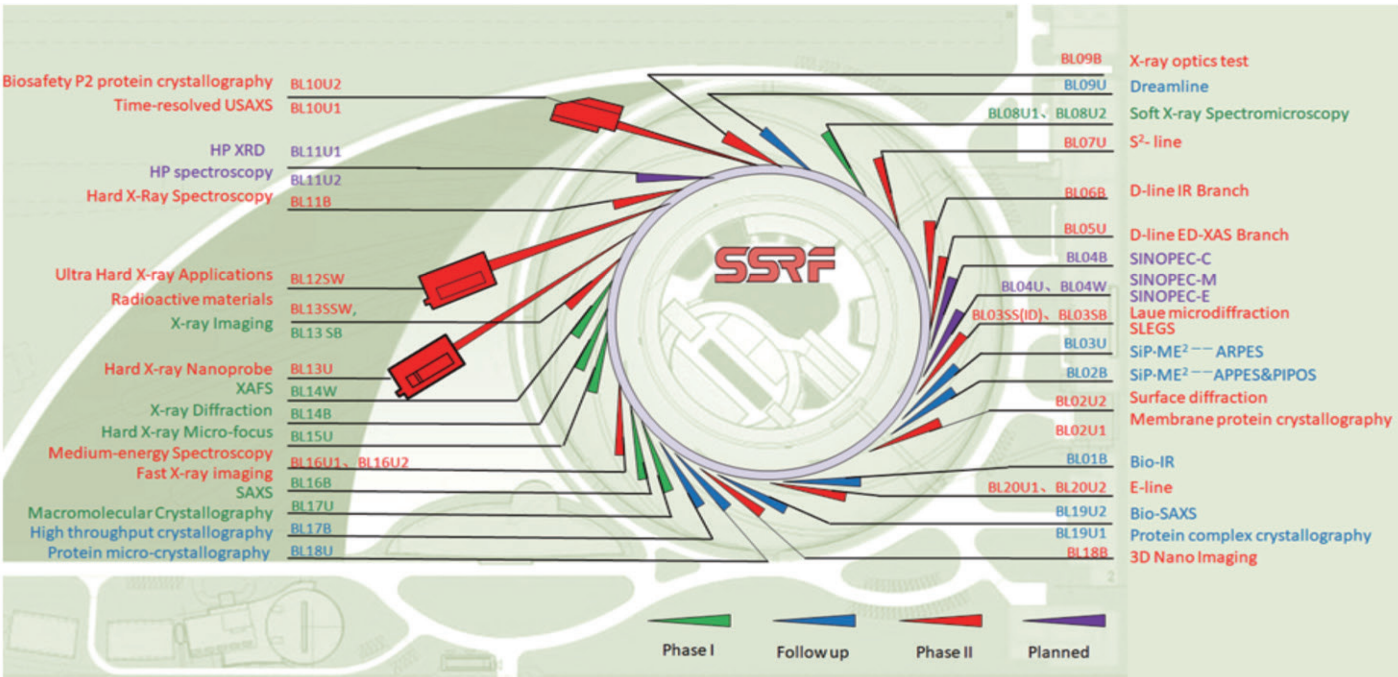
The SSRF Phase-II Beamline Project is a key national scientific infrastructure project, including the construction of sixteen state-of-the-art beamlines, accelerator upgrades, and experiment-supporting labs. It aims at improving substantially the experimental capabilities at SSRF particularly for the fields of energy science, environmental science, materials science, life science, medical science and industrial applications. The construction started officially in November 2016 with a construction period of 6 years.

The accelerator upgrade includes implementation of the super-bend based ring lattice configuration to increase the number of straight sections and the critical photon energy of the bending magnet radiation. So far the new storage ring has been operation since October 2019. Commissioning for new beamlines started from the end of 2018 and one of these beamlines, the hard X-ray spectroscopy, has opened for users.

SSRF Phase-II Beamline Project will be achieving new approaches such as multiple photon-energy-zone combination technology, near-limit capability for the third generation synchrotron radiation methodology, long beamlines skills and theirs applications, as well as one-stop service including *in-situ* equipment and off-line supporting labs. All these capabilities help SSRF to keep at the forefront of scientific researches and industrial applications. In the future, SSRF will be anticipated to accommodate more than 5000 users and 10000 person-times per year.

Phase-II beamlines

* Energy materials (E-line)
* Dynamics (D-line)
* BSL-2 crystallography
* Radioactive materials
* Compton gamma-ray source (SLEGS)
* Membrane protein crystallography
* Time-resolved USAXS
* Hard X-ray nano-probe
* Medium-energy X-ray spectroscopy
* Ultra hard X-ray applications
* Spin- and spatial-resolving spectroscopy
* Laue micro-diffraction
* 3D nano imaging
* Surface diffraction
* Fast X-ray imaging
* Hard X-ray spectroscopy



SHANGHAI SOFT X-RAY FREE-ELECTRON LASER

General Information

SXFEL-TF

* Beam energy: 0.84 GeV

* FEL wavelength: 8.8 nm

* Facility length: 293 m

SXFEL-UF

* Beam energy: 1.5 GeV

* FEL wavelength: 2-10 nm

* Facility length: 532 m

Undulator lines

* Seeded FEL line

* SASE FEL line

End-stations

* Cell Imaging

* Atomic, Molecular and Optical Physics

* Ultrafast Physics

* Surface Chemistry

* Photon-Electron Spectroscopy

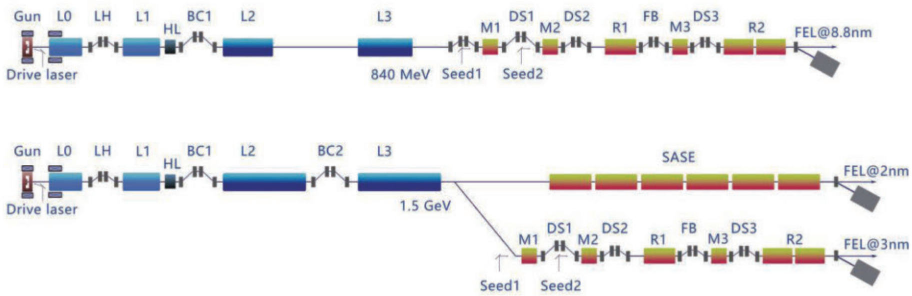
Overview

The Shanghai Soft X-ray Free-Electron Laser Facility (SXFEL) is the first Chinese coherent light source in the wavelength range of 10 nm to 2 nm. It is based on a 1.5 GeV normal conducting high gradient C-band linac and currently contains two FEL beamlines, a seeded FEL beamline and a SASE (self-amplified spontaneous emission) beamline, and five experimental stations.

SXFEL is being developed at the SSRF campus in two steps, named the SXFEL test facility (SXFEL-TF) and the SXFEL user facility (SXFEL-UF).

Currently, the 0.84 GeV linac based SXFEL-TF is under beam and FEL commissioning, aiming to test the related key technologies and the two-stage cascaded HGHG-HGHG or EEHG-HGHG (high-gain harmonic generation, echo-enabled harmonic generation) scheme.

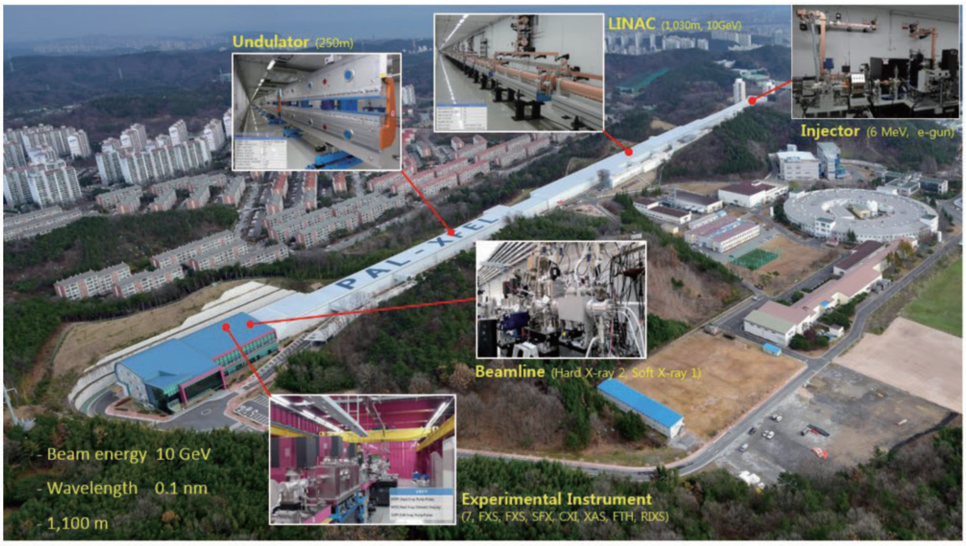
In the meantime, the user experiments oriented SXFEL-UF is being developed at a designated wavelength down to the water window region, towards starting the user service in 2020.



Pohang Accelerator Laboratory

General Information

Address : 80 Jigokro-127 beongil, Pohang, Gyeongbuk 790-834, Korea
Funded by : MSICT(Korean Gov.), POSCO, POSTECH
Facilities : PLS-II(Pohang Light Source-II) & PAL-XFEL
Name of Director : In Soo Ko



2019
PLS-II user service (35 BLs)
Pal-XFEL user service (3 BLs)

2018
30th Anniversary of the PAL

2017
PAL-XFEL user beamtime started

2012
Mar: PLS-II user service (30 BLs)

2011
PLS-II Upgrade completed
Started the project of PAL-XFEL construction (2011-2015)

2009
PLS-II (3.0 GeV) Upgrade project started (2009-2011)

2008
20th Anniversary of the PAL

2003
Storage ring beam energy upgrade to 2.5 GeV including injector linac

1995
PLS user beamtime started

PLS-II

User operation started in 2012 (PLS started in 1995)

3 GeV, 250~400 mA Top-Up operations within 0.5 % beam current variation

5,315 hrs of operation with 4,095 hrs user time, and 90 % availability in 2018

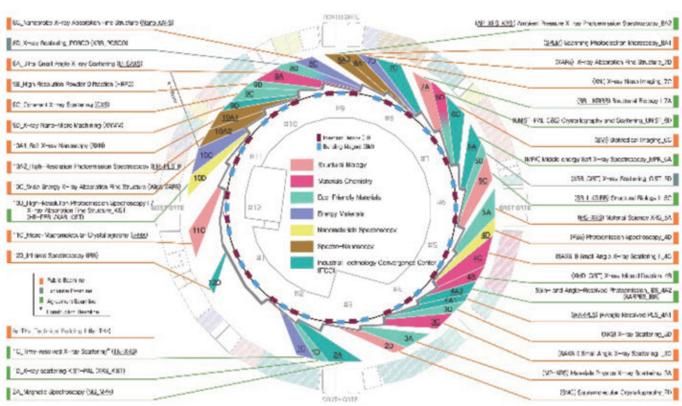
Operations Budget: ~50 M$ (USD) in 2019 FY.

6,096 visiting users in 2019.

2,271 proposals submitted, 1,767 approved in 2019.

User affiliation: 4.6% from abroad, 11.3% from national/public institutes, 72.8 % from universities, and 11.3 % from industries

Beamline Map



(35 beamlines are in operation, one is under construction)

PAL-XFEL

Project period: 2011 ~ 2015

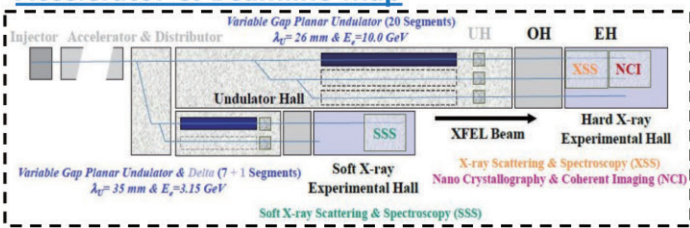
Accelerator: S-band (copper structures & SLEDs are used), 11-GeV electron linac, 51 klystrons-modulator sets (1 for X-band linearizer)

FEL lines: 2 hard (XSS, NCI) & 1 soft X-ray (SSS)

146 proposals submitted, 54 approved in 2019

Overall length	1100 m (linac: 750m, undulator hall: 250m, beamline: 100 m)
Beam charge / slice emittance	0.2 nC / 0.4 mm-mrad
Peak current / repetition rate	3 kA / 60 Hz
Electron gun	PC RF-gun
Bunch compression	3 chicane-type BCs at 0.33 GeV, 2.52 GeV, and 3.45 GeV
No. of S-band structures	174
No. of quadrupole magnets	204
Undulator type	Out-vacuum, variable gap (min. 8.3 mm)
Wavelength range : HX1 SX1	0.6 ~ 0.06 nm (linear pol.) 4.5 ~1 nm (linear pol.)
Photon pulse length	5 ~ 50 fs
Photon flux @ 0.1 nm	> 7.0 E+11

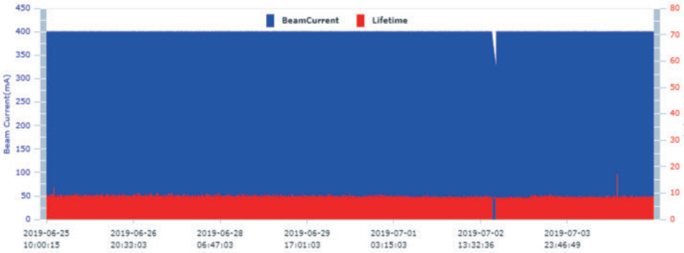
Accelerator & Beamline Map



Pohang Accelerator Laboratory

Current Activities of PLS-II

Operation status of the PLS-II

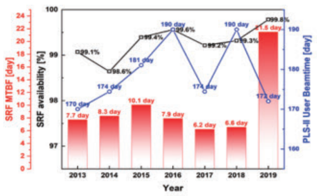


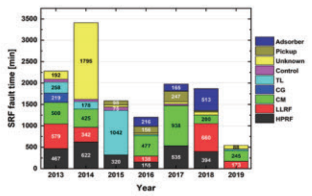
At the beginning of PLS-II, the electrons were stored on decay mode in 2012. Top-up mode was started at 2013. The storage ring has been gradually stabilized, and 4 perfect beam service periods without dump for 10 days were recorded in 2019.

In 2019, PLS-II provided beam service of 172 days. 13 BM(bending magnet) beamlines and 22 ID(insertion devive) beamlines were operated. The stored electron beam current of the top-up was 250~400mA.

The beam will be more stabilized by the tuning of electron orbit and the feedback system of photon beam.

PLS-II SRF operation status





SRF operation is getting more stable in PLS-II. The mean time between failure (MTBF) is longer than 20 days and the SRF availability is higher than 99% in 2019. A vacuum leak occurred in September 2019 during cool-down of the cryo module CM-3. Therefore, PLS-II has to be operated at low beam currents(250mA) until the module is reinstalled .

Machine Improvement project

Laboratory new projects are started in 2020

■ Conceptual design of 4th generation storage ring
- New ring with low emittance
- 100 pm emittance with 4 GeV electron beam

■ EUV lightsource & Diagnostic Instruments for industrial applications
- UV mask test instrument
- Study for super-bend

Major parameters of the PLS-II

Parameter	Value	Parameter	Value
Beam Energy	3 GeV	Emittance	5.8 nm·rad
Beam Current	360 ~ 400 mA	Tune (H/V)	15.36~15.38/9.145
Lattice Structure	Double-Bend	RF Frequency	499.96 MHz
Super-Period	12	Energy Spread	0.1 %

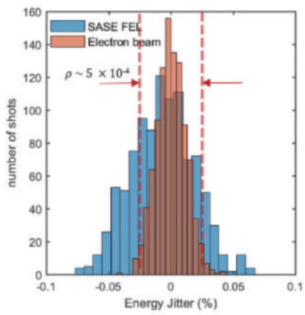
Current Activities of PAL-XFEL

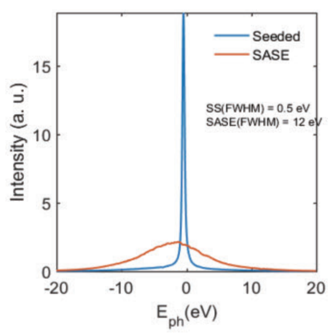
Operation status of the PAL-XFEL

PAL-XFEL successfully achieved the design value on 20 March 2019. FEL intensity is well maintained above 1 mJ at the photon energy 2~14.5 keV for user experiments. We also achieved 0.5-mJ FEL intensity for 20 keV FEL. The relative energy jitter of electron beam is as small as $1.2\text{x}10^{-4}$ and the relative photon wavelength jitter is $2.4\text{x}10^{-4}$ in rms.

Self-seeding was successfully commissioned to start the user service operation in 2019. It is found that a laser heater improves spectral purity and brightness of the seeded FEL with the peak intensity 9 times higher than SASE. The lowest (3.5 keV) and the highest (14.4 keV) photon energy self-seeding were also demonstrated. The highest intensity of seeded FEL is 0.85 mJ at 9.7 keV. A higher intensity is expected with more undulators. One spare HX undulator is ready to be installed in July 2020.

The position jitter of FEL beam is smaller than 10% of the FEL beam size and the pointing jitter of FEL beam is as small as 0.14 μrad in rms. Complex wavefield reconstruction using the seeded FEL was successfully done by the ptychography imaging. Seeded beam of PAL-XFEL turns out to be highly stable in energy as well as pointing and wavefront, as the algorithm showed excellent convergence with a single, constant mode. Ptychography imaging generates images by processing many coherent interference patterns measured by moving the sample with the specific distance.





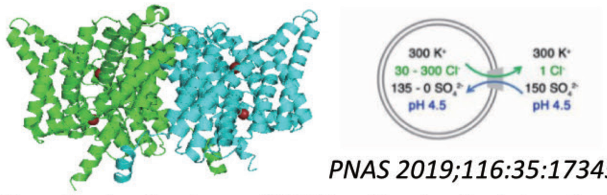
Achieved parameters of hard and soft X-ray FELs

Parameter	Hard	Soft	Unit
FEL radiation wavelength	0.062	1.0	nm
Electron energy	10.5	3.0	GeV
Pulse repetition rate	60	60	Hz
FEL intensity	0.5	0.3	mJ
Photons per pulse	1.5	15.0	10^{11}

Pohang Accelerator Laboratory

Research Activities of PLS-II

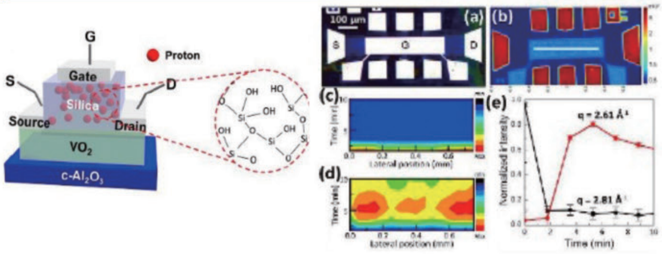
Crystal Structures of CLC Cl-/H+ antiporter



PNAS 2019;116:35:17345

The atomic structure of CLC antiporter is determined at 2.7Å resolution. The CLC membrane protein family is involved in a various cellular processes by controlling the cellular concentration of chloride ions. The researchers at Korea KBRI have shown that GLUex, an important glutamate residue, plays an important role in the transport cycle of chloride ions.

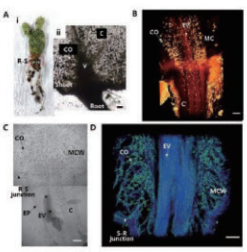
Gate-induced massive and reversible phase transition of VO2 channels



Adv. Funct. Mater. 2018; 28:39:1802003

The gate-induced three-terminal conductance modulation by a solid-state proton electrolyte was achieved by exploiting the reversible H+-induced MI transition in VO2 channels. The heavy protonation in a devices exhibited two-step I-to-M-to-I phase transition at RT. The structural and compositional characterization with spatial resolution demonstrated that large numbers of H+ ions were injected by gate bias into the VO2 channel without creating oxygen deficiencies, and this H+-induced electrochemical phase transition simultaneously triggered giant modulation of the out-of-plane lattice.

Hydraulic strategy of cactus root–stem junction for effective water transport



Frontiers in Plant Science 2018;9:799

This study contributes to the understanding of the hydraulic survival strategy of cacti.
Because cacti store considerable amounts of water in their stem for several months under continuous drought conditions, these distinct hydraulic strategies are likely to be crucial for their survival.

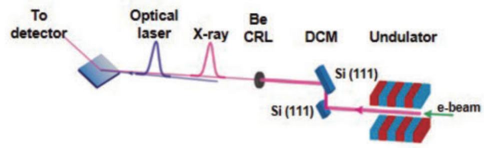
Activities of PAL-XFEL beamline

Experimental Stations & Instrumentations

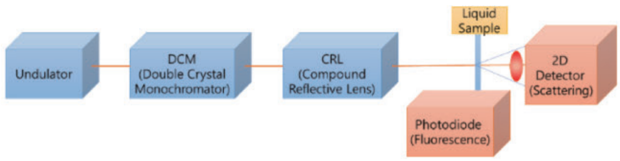
From 2020, three beamlines including seven scientific instrumentations will be available to PAL-XFEL users.

Beamline	End-station
XSS (HX)	Femtosecond X-ray Scattering (FXS) Femtosecond X-ray Liquidography (FXL)
NCI (HX)	Coherent X-ray Imaging (CXI) Serial femtosecond Crystallography (SFX)
SSS (SX)	Soft X-ray Absorption Spectroscopy (XAS) Soft X-ray Emission Spectroscopy (XES) Resonant Soft X-ray Scattering (RSXS)

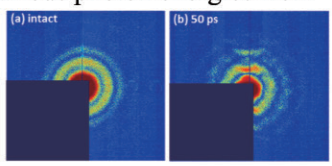
FXS : The X-ray diffraction for condensed matter physics and material science. This research capability at ambient pressure is now extended to low temperature (>20K) and vacuum condition.



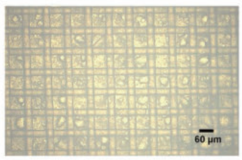
FXL : Ultrafast phenomena on time-resolved X-ray solution scattering and absorption spectroscopy. Light induced molecular structural changes/electronic state changes can be explored with ~150 fs temporal resolution.



CXI : Time-resolved coherent diffraction imaging under vacuum or He-ambience for various photon energies from tender to hard X-ray. We provide a fixed target method up to 60 Hz scan speed.



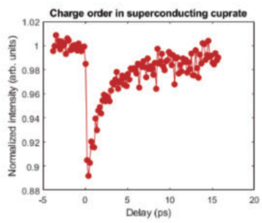
SFX : Development of a fully hydrated 2D fixed target sample delivery system to increase experiment efficiency (sample consumption, preparation time, etc.).



Glucose Isomerase

XAS/XES : Dynamic phenomena related to excited carriers on solid, gas, liquid phase materials. Recently, excited state dynamics of catalytic materials was mainly examined.

RSXS : The time-resolved investigation of complex electronic orders, i.e. charge, spin, and orbital ordering in quantum materials.



Pohang Accelerator Laboratory

Synchrotron Radiation for the Future of Science

Pohang Accelerator Laboratory

Every big Science facility has similar missions that are to enable internationally leading research, to operate as the user facility accessible to diverse spectrum of researchers, and to fulfill the scientific and technical needs for the challenges faced by the society through research.

Through the construction and operation for the last 20 years, PLS, PLS-II also have played a key-role for the developments in vacuum industry, semiconductor industry, civil engineering, surveying, and even building technology of Korea. It has actively contributed to the developments in chemical engineering and biotechnology, which directly affects the industry and the people's life.

As the Korean President suggested in 2018 at PAL - “Power of Science, Power of Imagination, Future of Korea!”-, We will continue to do our best to help scientists solve the major challenges facing the 4th industrial revolution and provide science and imagination.

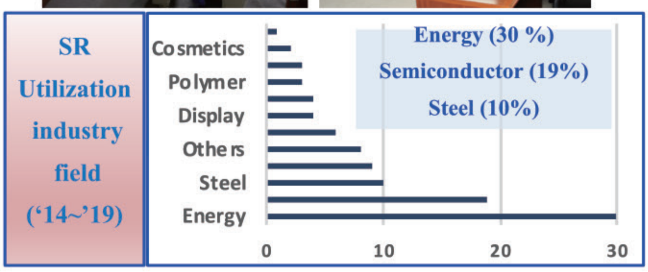
We would like to express our sincere gratitude to MSICT(Ministry of Science and ICT) and KOSUA(Korea Synchrotron Radiation Users’ Association).

과학기술정보통신부
Ministry of Science and ICT

KOSUA 사/단/법/인 한국방사광이용자협회

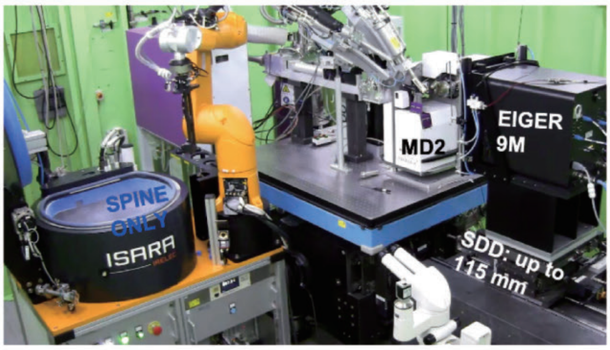
Industrial Technology Convergence Center

ITCC was established to expand industrial applications of synchrotron radiation and analytical techniques. ITCC provides technological consulting, synchrotron radiation measurements and data analysis for large & medium sized companies. Various fields of industries have been supported in collaboration with PAL as follows:



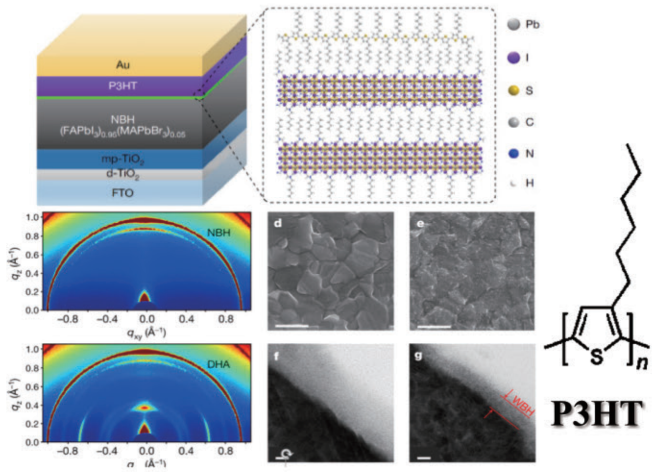
Structural Biology

The protein crystallography beamline BL5C is equipped with the high capacity sample exchanging robot and a photon countable X-ray detector EIGER 9M in 2019. Based on these advanced instruments, the beamline achieved high throughput and also high automation in the protein crystallography experiments. The automated protocol enable you to collect more than 400 data sets per day without staff.



Renewable Energy & Environment

Perovskite solar cells are currently the fastest-advancing solar technology, exceeding the maximum efficiency achieved in silicon solar cells in 2019. The researchers at UNIST in Korea reported that the double-layered halide architecture (DHA) of perovskite solar cells showed excellent stability and high performance of 16.3% for 1000 hours. These results indicate that the excellent optoelectronic properties of P3HT are inexpensive and likely to be perovskite solar cells for commercialization based on ease of manufacture. The formation of DHA layer was confirmed by GIWAXS measurement of BL6D at PLS-II. The results were published in Nature in 2019.



Nature, 567, 511–515 (2019)

NSRRC

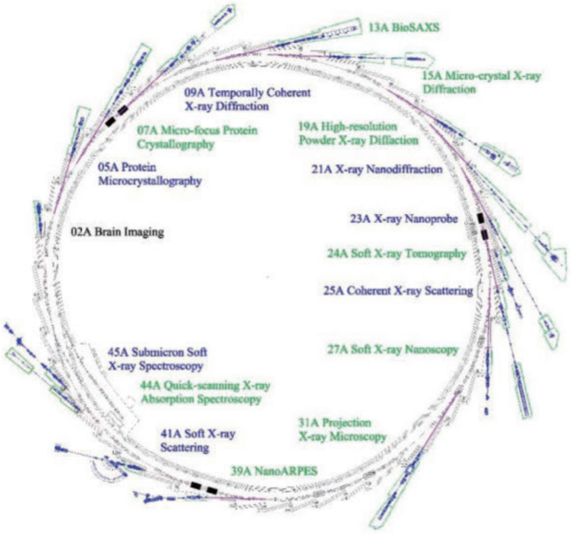
General Information

Located in the Hsinchu Science Park in Taiwan, the National Synchrotron Radiation Research Center (NSRRC) has been operating its first high-performance synchrotron light source, the Taiwan Light Source (TLS), since 1994. NSRRC provides broad spectra from IR to X-rays of great brightness that is unattainable from conventional laboratories, drawing users from academic and technological communities worldwide. Each year, scientists and students pay more than 10,000 visits to the NSRRC to perform experiments in various scientific fields, using cutting-edge technology and equipment. These endeavors aim to explore the vast universe, to scrutinize the complicated structures of life, to discover novel nanomaterials, to create a sustainable environment, to unveil things living in the distant past, and to deliver better green energy materials to mankind.

- ☐ TLS: 1.5 GeV 360 mA top-up operations, user operations started in 1994; TPS: 3 GeV 500 mA top-up operations, user operations started in 2016
- ☐ TLS operations in FY 2019: 5,187 hours of operation with 104,576 hours user time (23 beamlines combined) and 120.4 hours down time
- ☐ TPS operations in FY 2019: 4,635 hours of operation with 19,672 hours user time (7 beamlines combined) and 75.3 hours down time
- ☐ Operation budget (including TPS Beamline construction): US$56.5 million in FY2019, US$54.62 million in FY2018 (1USD = 32.27TWD)
- ☐ 2,432 users in FY 2019
- ☐ 3,005 proposals submitted, 2,025 approved (67.39 %) in FY 2019
- ☐ User affiliation: 16.94% from abroad, 83.06% from domestic institutions in FY 2019
- ☐ 390 SCI papers published in FY 2019 (124 papers in top 5% journals)

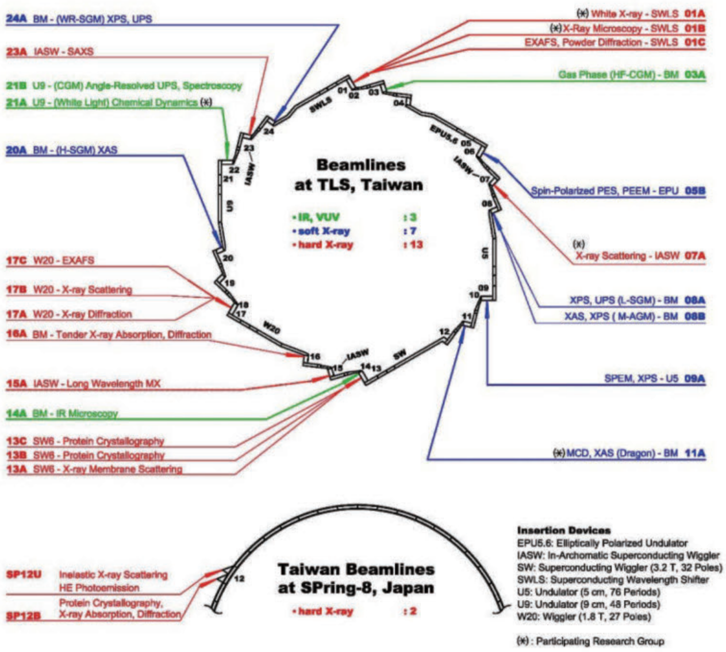
Aerial view of TLS and TPS rings

TPS Phase I (blue) and II (green) Beamline Layout



Schedules for TPS beamlines:

- 7 beamlines have been open to general users
- 3 beamlines will be open to general users in 2020



23 beamlines in operation at TLS and 2 beamlines at SPring-8

Current Activities

TLS has been available to domestic and foreign researchers since April 1994. At the present, there are 23 beamlines with broad spectra covering infrared, vacuum ultraviolet, soft X-ray and hard X-ray. In addition, NSRRC operates 2 Taiwan Contract Beamlines at SPring-8 in Japan. Since the inauguration of the TLS user program, the number of user-stints from users worldwide has reached extremely high level annually in terms of both the quantity and quality of scientific research outputs and applications, conducting a sizable amount of world-class experiments in many fields.

Domestic and international researchers have been applying the light source broadly to diverse fields of basic and applied science since the launch of operations. TLS has become a world-class research facility given its operation quality, substantial research results, and international collaboration. TLS has set numerous world records and is known as:

- the first third-generation synchrotron light source in Asia
- the second synchrotron light source being equipped with a superconducting radio frequency cavity in the world
- the fourth synchrotron light facility in the world operating in top-up mode
- the synchrotron light source with the densest insertion devices worldwide

TLS storage ring building.

With rapid advancements in global technology as well as increasing demand from users, the NSRRC secured approval from the Taiwanese government to build the Taiwan Photon Source (TPS), which establishes a new, low-emittance synchrotron light source on the current campus with an electron beam energy of 3 GeV, a circumference of 518 meters, and a 24-DBA-cell design. The ground-breaking ceremony for the TPS project was held in February 2010. During nearly 5 years of civil construction, accelerator design and manufacturing, and beamline development, the TPS delivered its first synchrotron light on the last day of 2014. Together with bright synchrotron X-rays, seven phase-I beamlines equipped with state-of-the-art instruments and innovative techniques have been available for academic and industrial users to conduct their research since the dedication ceremony of TPS in September 2016. The beamlines that come on-line in phase I and II of TPS operation are:

Phase I beamlines

- 05A protein microcrystallography
- 09A temporally coherent X-ray diffraction
- 21A X-ray nanodiffraction
- 23A X-ray nanoprobe
- 25A coherent X-ray scattering
- 41A soft X-ray scattering
- 45A submicron soft X-ray spectroscopy

Phase II beamlines in operation

- 02A brain imaging
- 24A soft X-ray tomography
- 44A quick-scanning X-ray absorption spectroscopy

Dedication ceremony for the new experimental facility of TPS.

Future Activities

TPS has been available to the academic and scientific communities to conduct advanced research since September 2016. Now TPS is in daily operation with a stable electron-beam current of 500 mA using a top-up injection scheme and reaches its the final designed goal of electron-beam current in TPS. Following the seven initial phase I beamlines, ten phase II beamlines are currently operational (3) or under commissioning and construction (7) and nine phase III beamlines are planned to be completed before 2026. Considering the complementarity nature of TPS and TLS, the operation plan for the two facilities will take multiple factors into consideration, such as source characteristics, beamline functionalities of the two light sources, scientific opportunities, user communities, and potential for economic development.

Looking forward to the advances of TPS, we plan:

- to make TPS one of the brightest synchrotron light sources in the world and a premier interdisciplinary experimental facility
- to develop innovative experimental techniques and to expand the fields of scientific research, especially in biomedicine and nanoscience technologies, to catapult academic research in Taiwan
- to assist high-technology industries in their research and development of products and in optimization of production processes, which in turn will improve our country's international competitiveness in the knowledge economy
- to attract more international research groups to conduct experiments at NSRRC, to build beamlines jointly, and to promote international collaboration
- to provide an important incentive for international scientists to engage in long-term advanced interdisciplinary research in Taiwan
- to entice and foster students to devote themselves to advanced research that can lead to important scientific discoveries

Both TLS and TPS offer their own unique advantages to deliver synchrotron radiation of great quality over a broad spectral range. TLS is a 1.5-GeV third-generation storage ring with low- & medium-energy that provides an optimum source of photons in the IR, VUV and soft X-ray regions. TPS is a 3 GeV medium-energy storage ring, which is optimized for the hard X-ray region. For instance, the photon flux of VUV at TLS is better than that at TPS. However, when it comes to the hard X-ray region, TPS is superior to TLS.

Phase II beamlines under construction are:

- 07A micro-focus protein crystallography
- 13A biological small-angle X-ray scattering
- 15A micro-crystal X-ray diffraction
- 19A high-resolution powder X-ray diffraction
- 27A soft X-ray nanoscopy
- 31A projection X-ray microscopy
- 39A nanoARPES.

The planned phase III beamlines are:

- dragon
- tender X-ray absorption spectroscopy
- ambient pressure X-ray photoemission spectroscopy
- soft X-ray absorption spectroscopy
- high-resolution X-ray absorption spectroscopy
- X-ray absorption spectroscopy
- powder X-ray diffraction
- in-situ serial protein crystallography
- small-angle X-ray scattering.

TLS provides an optimum photon source in the VUV and IR regions, and is an outstanding scientific research facility for photophysics and photochemistry in space science, photochemistry for atmospheric science, chemical dynamics, photodecomposition, free radicals, interstellar chemistry, energy transfer of highly vibrationally-excited molecules, paleontological fossils, cancer screening, and the development of cutting-edge cancer therapies.

In addition to the scientific potential of photon beams, to provide TLS with new competitive advantages, a TLS booster ring with high operation efficiency could be developed into a proton or carbon ion medical accelerator, allowing exploring the use of medium-energy proton beams for industrial and medical applications.

NSRRC

Synchrotron Radiation for the Future of Humanity

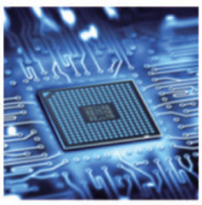
Synchrotron light sources were originally built and dedicated for scientific research. However, the ultimate goal of these advanced facilities is to offer human beings a better life with a smart, healthy, and sustainable future. To achieve that, we have cooperated with academic and industrial leaders to implement pioneering research in order to bridge the scientific fundamentals to the benefit of society. Green energy, biotechnology, and pharmaceutical drug design are among the major areas directly impacting our lives.

Green Energy

Green-energy technologies include research for improving energy conservation, generation, and storage. Taiwan has no natural energy resources, such as coal, gas, or oil. Thus, research in green-energy is an inevitable path to providing a clean and sustainable future. NSRRC uses XAS and PES techniques to help domestic companies improve the quantum efficiency of solar cells through comprehensive understanding of their electronic structures. We also apply SAXS and TXM techniques to reveal polymer structures and to assist companies with developing energy-saving sustainable tires with low-friction. These two applications strengthen their global competitiveness and help to create a green environment with a completely new approach.

Metal is actually a 100% recyclable, sustainable material. NSRRC also collaborates with several universities to develop new types of high-strength steel (HSS) and to establish several in-situ analytical platforms under stress loading and thermal treating. For the automotive industry, applying HSS can reduce the weight, and then save the energy consumption up to 25%, which is particularly important for electric. In addition, the Taiwan Strait has one of the best wind fields in the world. A giant windmill plant (~3GW) is scheduled to be built before 2025, and of course, high-quality metals will be used as fundamental building blocks.

We also cooperate with semiconductor companies in Taiwan, using various SR techniques to develop next-generation lithography and NC (negative capacitance) FET technologies. These two applications aim to fabricate nano-chips with high-efficiency and ultra-low power consumption, which will surely play an important role in the coming IoT (internet of things) applications that will impact our daily lives.

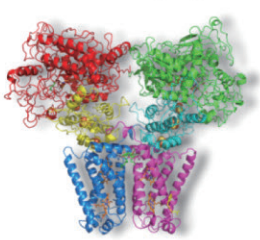


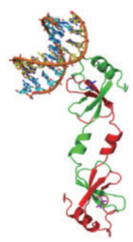
One petrochemical company and one research institute have used SR XRD and EXSAF techniques to investigate catalysts for higher-efficiency, less-polluting production. We also used several SR techniques to study an electrode material for the Li-ion battery in support of a domestic company to acquire patents and to successfully open global markets. All these SR research activities enable domestic companies to pursue clean/energy-conserving production or application-based production based on the understanding of the characteristics of key materials.

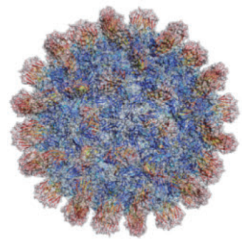
Biotechnology and Pharmaceutical Drug Design

Structure-based drug design has played an important role in drug discovery because of its efficiency in reducing development time. This approach promises the development of new drugs, which exhibit higher specificity toward targeted diseases with fewer side effects. The lead compounds can be modified atom-by-atom to fit their specific targets through visualizing the three-dimensional structure of the target protein-drug complex using X-ray protein crystallography (PX). Many pharmaceutical companies and health research institutes have been executing structure-based design programs, and are steadily intensifying efforts in this area, including:

- the companies affiliated with the Japan Pharmaceutical Manufacturers Association (JPMA) have used NSRRC PX beamlines to conduct drug development
- the Taiwan biotech companies have performed experiments at NRRRC PX beamlines for pharmaceutical applications
- the Taiwan biotech companies have invested R&D budget and collaborated with NSRRC scientists for an industrial project







In summary, NSRRC is devoted to frontier scientific research to develop advanced energy and biopharmaceutical technologies. We hope these endeavors help us to establish a cleaner, healthier, and more sustainable future.

SPring-8 & SACLA

General Information

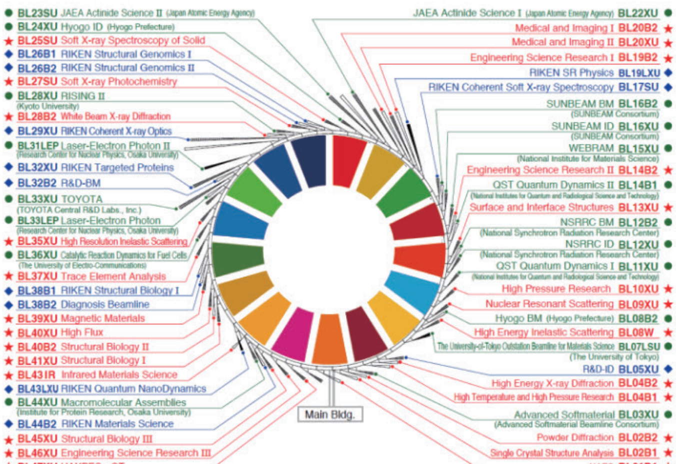
The SPring-8/SACLA complex, consisting of a third-generation SR and a SASE-XFEL, is an international center of excellence for high-energy photon science. Since 1997, SPring-8 has delivered brilliant X-rays for a variety of experimental stations. SACLA, which was inaugurated in 2012 as the world's first compact XFEL facility, offers ultrafast, intense X-ray pulses for specialized experiments. The unique capabilities and synergistic combination of these light sources provide outstanding development opportunities for a wide range of advanced research and innovation. An enhancement underway will further increase our capabilities: for the 8-GeV linac at SACLA, we are replacing the old injector consisting of a 1-GeV linac and an 8-GeV booster synchrotron with electron injection into SPring-8.

SPring-8

- commenced user operations in 1997
- photon energy ranging from 0.1 to 200 keV
- an 8 GeV, 100 mA with < 0.1% current variation from top-up operations
- 5,317 hours of operation with 4,560 hours user time achieved (vs. 4,608 hours planned) and 98.9% beam availability in FY 2018
- operating budget of 9.47 B JPY (~US$88 M) in FY 2018
- 17,011 visiting users in FY 2018 - in FY 2018 we welcomed our 250,000th user since 1997
- 1,913 proposals submitted with 1,463 approved (76.4%) in FY 2018
- user affiliation: 9.1% international, 16.7% from national/public institutes, 53.8% from universities, and 20.4% from industry in FY 2018
- ~1,000 publications/year in refereed journals

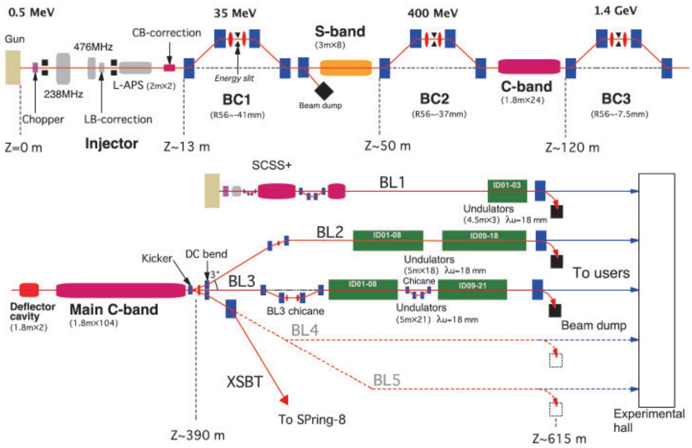
SACLA

- commenced user operations in 2012
- photon energy ranging from 4 to 20 keV
- pulse duration ~7 fs
- 6,281 hours of operation with 6,270 hours user time, and 221 hours downtime (~3.5% of user time) in FY 2018
- operating budget of 5.64 B JPY (~US$56 M) in FY 2018
- 1,296 visiting users in FY 2018
- 174 proposals submitted with 112 approved (64 %) in FY 2018
- user affiliation: 34.7% international, 61.8% from national/public institutes & universities, and 3.5% from industry in FY 2018
- 423 publications in refereed journals since FY 2012



SPring-8 Beamline Map

57 beamlines are in operation and 5 are awaiting construction



SACLA Accelerator & Beamline Map

3 beamlines are in operation

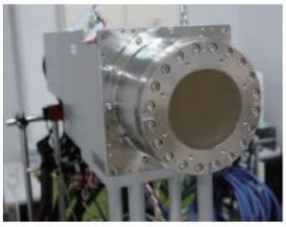
SPring-8 & SACLA

Current Activities

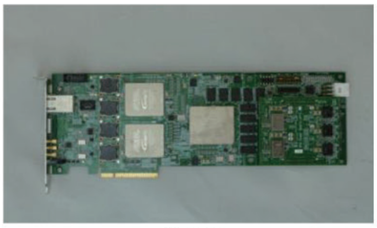
SPring-8, along with other synchrotron radiation facilities, has seen its user base evolve over the years. Utilization by users from industry has increased dramatically over the past 23 years and, at the same time, the number of users from fields historically far from conventional synchrotron radiation has grown significantly. Also, a growing number of researchers do not want to conduct synchrotron radiation experiments themselves, but want access to data from synchrotron radiation research. To respond to these types of changes, SPring-8 is using robots to automate the measurement equipment and to provide measurement support.

SP8 Robots

Automated measurement requires highly reliable measuring equipment, with X-ray detectors of particular importance. Conventional wisdom says that increasing the performance of the detector by a factor of 10 is almost equivalent to increasing the performance of the light source by a factor of 10, but costs about one tenth as much. SPring-8 has developed MPCCD detectors for the SACLA XFEL, and is developing CITIUS detectors for the upcoming SPring-8-II storage ring source. In parallel, SPring-8 is developing a novel data acquisition system to process the coming explosion of data. Discussions are underway to develop a high-speed, large capacity network between SPring-8 and the FUGAKU supercomputer in Kobe.

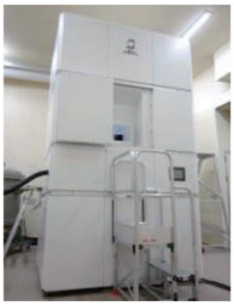


MPCCD

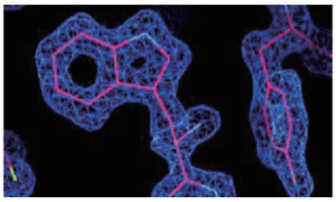


CITIUS

Our new generation of users is also requesting various off-line instruments to complement their SR work. One of the most popular requests is for a cryo-electron-microscope (cryo-EM) to be used for protein structure determination. SPring-8 has collaborated with a domestic company to develop a new type of cryo-EM using a field-emission cold cathode electron gun to enhance spatial resolution. In 2019, this EM achieved 0.15 nm resolution, a world-record resolution at that time.



JEOL CRYO ARM 300



1.5 Å-resolution single particle of mouse apoferritin

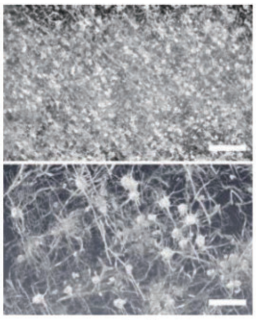
One of the new areas of research at SPring-8 is forensic science. SPring-8 has supported many forensic investigations since it was first used in 1998 to analyze poisons in the Wakayama arsenic incident. A group was established in the RIKEN SPring-8 Center in 2018 to facilitate the systematic study of forensic science. The group collaborates with police agencies from all over Japan.

Forensic

Another exciting field of research is imaging. A wide variety of imaging schemes have been developed at SPring-8, including scanning probe imaging using the super-polished KB mirrors developed at Osaka University. Due to the large coma aberration, conventional KB mirror focusing cannot be used for most imaging. However, recently developed KB mirrors circumvent aberration problems. Development of new microscopes using these advanced KB mirrors is now underway.

An imaging project newly initiated is depicting the 3D connections among the synapses in the human brain. Most synchrotron radiation facilities in the Asia-Oceanic region are participating in this project, aiming to collaboratively map the 3D synapse connections in a human brain over next few years.

Imai, T. et al., Commun Biol 2, 399 (2019)

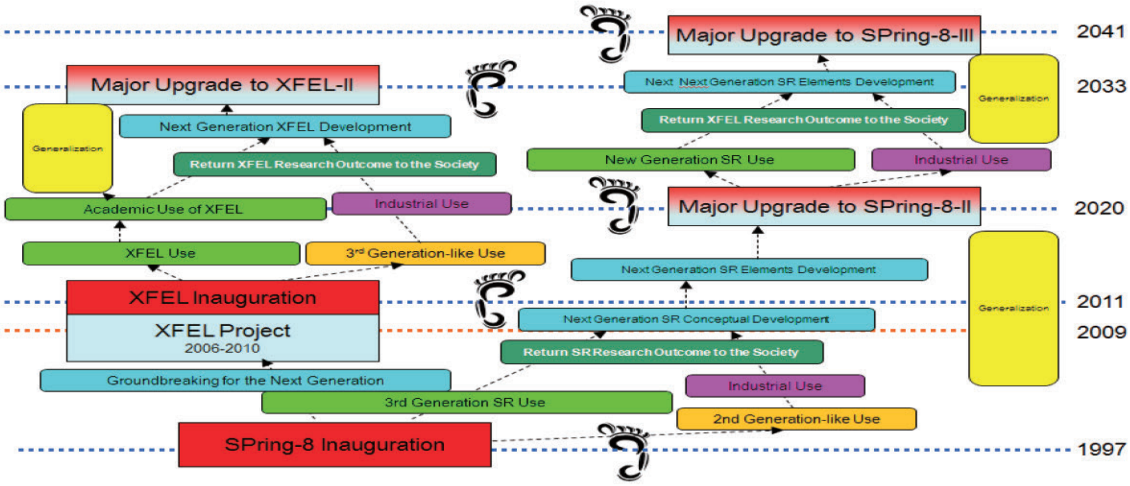


Mouse brain CT

Virtual reconstruction of birds based on fossil materials

Future Activities

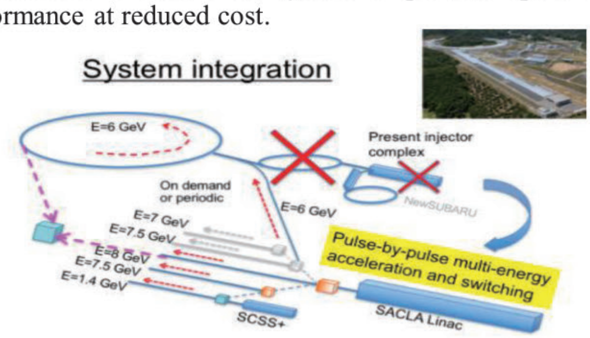
Operations at the Harima site began with the inauguration of SPring-8 in 1997. The site capabilities reached a higher level with SACLA's inauguration in 2012. The next great step will come with the renovation of SPring-8 in the 2020s. Future steps will include a high-repetition upgrade of SACLA in the 2030s, followed by a ring-type XFEL upgrade of SPring-8, hopefully, in the 2040s. We have already completed the first version of the conceptual design report for the upgrade plan for SPring-8, which we call the SPring-8-II project. The impetus behind SPring-8-II is to approach a nearly diffraction-limited storage ring under several boundary conditions, including reuse of the existing accelerator tunnel and most of the current beamlines. We expect to complete the SPring-8-II upgrade in the mid-2020s, revising the original plan as necessary in light of the progress of the upgrade projects at ESRF and APS.



When we started discussing the upgrade plan with users, one of the greatest concerns came from our users from industry, because shutting down SPring-8 would leave no third-generation Synchrotron Radiation sources in Japan. Many industrial companies have incorporated research at SPring-8 into their daily work. The Japanese research community responded to these concerns from industry by starting discussions about the construction of Japan's newest Synchrotron Radiation facility, SLiT-J in Sendai. The SPring-8 team is participating in the design and construction of the SLiT-J accelerators in collaboration with the National Institute for Quantum and Radiological Science and Technology (QST) as a kind of initial prototype for the SPring-8-II system.

Both SPring-8-II and SLiT-J are low-emittance storage rings based on multi-band-achromat (MBA) technology. One of the most challenging technical problems is how to construct a low-emittance injector compatible with the low-emittance ring. We decided to use SACLA's linac as the injector that provides low-emittance electron beams to the storage ring of SPring-8-II. This scheme has already been tested at the current SPring-8 facility, and will be applied to user operations in FY2020. The new injection system replaces the old one, which consisted of a 1 GeV S-band linac and a 8 GeV booster synchrotron, enabling a substantial reduction of maintenance and operation costs for the aging systems. However, retirement of the old system requires removal of the injection system used for the NewSUBARU storage ring operated by the University of Hyogo. SPring-8 has built a new 1 GeV linac with dual functions: an injector for NewSUBARU and R&D for the SLiT-J injector. In the future, this linac will be used for R&D for the SACLA upgrade project.

SLiT-J has accepted the injection scheme of SPring-8 and adopted a 3 GeV C-band linac as its full-energy injector. The injector system for SLiT-J is based on a modification of SACLA's C-band linac system to provide optimized performance at reduced cost.



Although the SPring-8-II upgrade project has not received official approval yet, renovation and reorganization of beamlines and end-stations have already started. Public and RIKEN beamlines will be renovated one by one over the next ten years. After some discussion, the major upgrade of SACLA planned for the mid-2030s will target increasing the repetition rate from the current 60 Hz to around 10 kHz without using the superconducting technology for the cavities. The team has started collaboration with a group from KEK toward this goal. In addition, development of a new thermionic electron gun for SACLA started, aiming to increase the pulse charge of the SACLA linac.

Development of a new undulator system for a ring-type XFEL has been initiated by using the NewSUBARU storage ring in collaboration with University of Hyogo. This system is one of the candidate undulators for the SPring-8-III upgrade planned for the 2040s.

SPring-8 & SACLA

The Futures of Synchrotron Radiation and Humanity

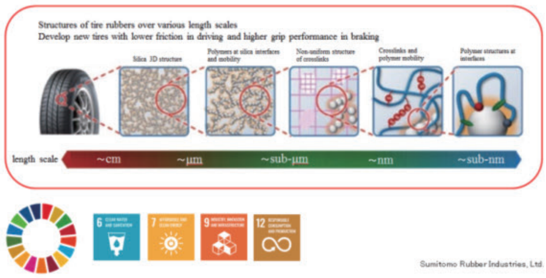
Synchrotron radiation provides short-wavelength light to explore the nano-world. It has been applied to a wide variety of fields in science and technology, leading to advances based on new knowledge of the nano-world at the atomic and molecular level. Starting from the earlier applications to vacuum-ultraviolet and soft-X-ray spectroscopies, the scope of use for synchrotron radiation has expanded rapidly, and has recently encompassed even fields such as archeology and forensic science.

For many of the phenomena around us, we understand *how* they happen, but we do not know *why* they happen. The brighter X-rays from next generation sources will be able to address many *"whys"* using the newly revealed knowledge about functions and activities at the atomic and molecular levels. Once we can understand *why* a phenomenon happens in atomic or molecular processes, we can then attempt to either enhance or inhibit it by manipulating those processes. We are all familiar with wear, friction, lubrication, breakdown, combustion, catalyst, adhesion, welding, and meltdown. However, atomic insights into these phenomena are generally limited. For example, if we could control the breakdown of a product, incorporating its eventual breakdown into its initial design, the methods of production would change drastically.

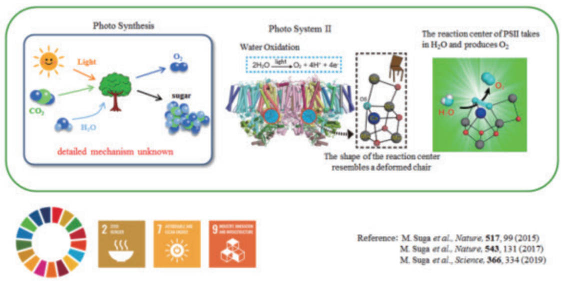
We confront many challenges regarding the sustainability of our society. For some of the more urgent problems, the United Nation has developed Sustainable Development Goals (SDGs) and encouraged cooperative efforts toward reaching the goals by 2030.

SPring-8 recently compiled our results in relation to the SDGs into a booklet. We reported that SPring-8's research has addressed fifteen of the seventeen SDGs. These results did not arise from the intentional pursuit of the SDGs, but the routine activity of SPring-8 that happened to align with the sustainable goals. The booklet includes more than 250 items, a couple of which we describe below.

The first example comes from an industrial collaboration. Using small-angle X-ray scattering (SAXS), an automobile tire company searched for the optimum molecular structure for the fillers in tires to suppress internal friction and, consequently, to reduce fuel consumption. A combination of SAXS analysis and dynamics simulations using a supercomputer led to the development of a new tire concept. The company launched the tire on the market as a "Fuel-Saving Tire." A second Japanese tire company followed, making this type of fuel-efficient tire a National Brand of Japan. This is one of many examples of research results that SPring-8 has contributed to energy conservation.



A second example is the determination of the structure of the water-splitting enzyme, Photo System II (PSII), and the electronic pathway responsible for splitting water molecules into oxygen and protons. The static structure of PSII was determined using SPring-8 and SACLA facilities. The dynamic process was analyzed at SACLA by producing intermediate states using pump laser pulses. The structural changes around the reaction center were fully analyzed to determine the precise intermediate states. The results are attracting great attention from the perspective of making artificial water-splitting catalysts powered by sunlight. The resultant oxygen and hydrogen atoms provide the energy source for fuel cells to produce electric currents. If we can develop high efficiency water-splitting catalysts, we could generate energy from splitting water molecules rather than by burning fossil fuels.



Reference: M. Suga *et al.*, *Nature*, **517**, 99 (2015)
M. Suga *et al.*, *Nature*, **543**, 131 (2017)
M. Suga *et al.*, *Science*, **366**, 334 (2019)

Although SPring-8 and SACLA are making progress on the SDGs, unfortunately these facilities consume huge amounts of energy for their daily operations, mostly due to the less efficient technologies that were available at the time of their construction. The renewal of the storage ring for the SPring-8-II upgrade will greatly reduce the energy consumption of the whole facility by 1/3.

Synchrotron Light Research Institute (SLRI)

General Information

The Synchrotron Light Research Institute (SLRI) is the site of the synchrotron facility located in Nakhon Ratchasima, Thailand [Figure 1]. Its accelerator complex houses the first synchrotron light source in Thailand. The Siam Photon Source (SPS) is an electron accelerator consisting of a 40 MeV linear accelerator (LINAC), a 1 GeV booster synchrotron (SYN), and a 1.2 GeV storage ring (STR) [Figure 2]. Currently, there are different measurement and fabrication techniques available to serve various research areas in basic sciences, applied sciences, and industry from the macro-scale down to the molecular/atomic scale. The Thai government has policy an interest in increasing investments for science and technology infrastructure, including the one for synchrotron facility. Notably, HRH Princess Maha Chakri Sirindhorn has paid her royal attention to the facility as one of important Thailand's infrastructures for science and science diplomacy.

Figure 1: SLRI is established as a public organization under the supervision of Thailand's Ministry of Higher Education, Science, Research and Innovation.

A beamline is a system of components, such as slits, monochromators, focusing mirrors, and other optical elements used for shaping and delivering synchrotron light from the storage ring to experimental stations. An experimental station, located at the end of each beamline, contains measurement systems for a specific measurement technique. SLRI currently has 10 beamlines with 12 experimental stations in routine operation and 3 beamlines with 4 experimental stations under construction [Figure 3]. The beamlines are available for users from Thailand and around the world. The accelerator complex was transferred from Japan two decades ago, while the beamlines and their end-stations were designed and built in Thailand. The beamlines have been equipped with sophisticated instruments to characterize materials in advanced research levels.

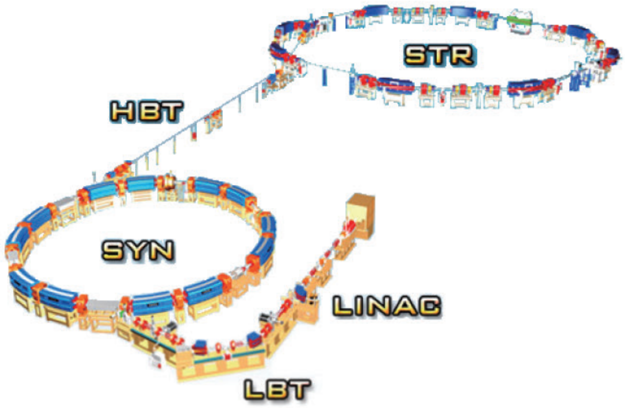


Figure 2: Accelerator layout

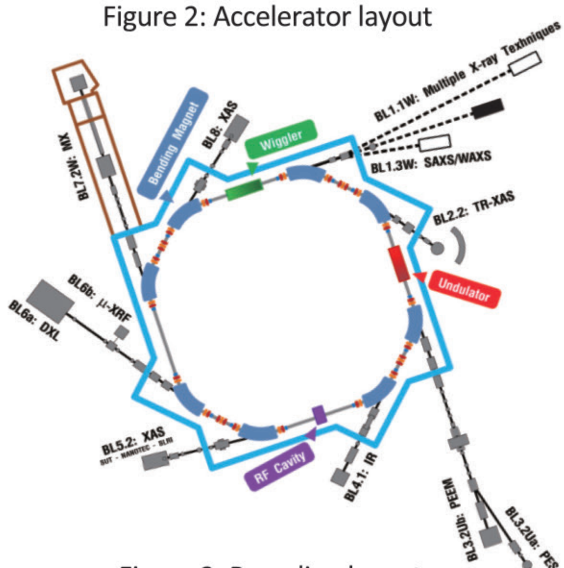


Figure 3: Beamline layout

Siam Photon Source (SPS) (FY 2019)

Circumference: 81.3 m

Electron energy: 1.2 GeV, 150 mA

Decay mode operation (Injection twice per day)

Beamtime: 4982 h

User time: 4882 h

Beam study time: 288 h

Preventive maintenance time: 432 h

Machine shutdown : 2616 h

Operation budget: 48 M THB (1500k USD)

Synchrotron Light Research Institute (SLRI)

Current Activities

SLRI has proposed its facility as the "ASEAN Synchrotron Facility" dedicating to serve researchers and scientists from ASEAN countries to utilize the synchrotron light research facilities at SLRI. The institute eagerly promotes collaboration among scientists in the region as well.

Academic Section

The numbers of proposal accepted from 2003 to 2019 have clearly been increased every year [Figure 4]. There have been 2831 proposals in total accepted since 2003. Most of the proposals are from academia and governmental laboratories. However, proposals from industries have tended to increase since 2019. This demonstrates the potential for developing Thailand's infrastructure using synchrotron radiation.

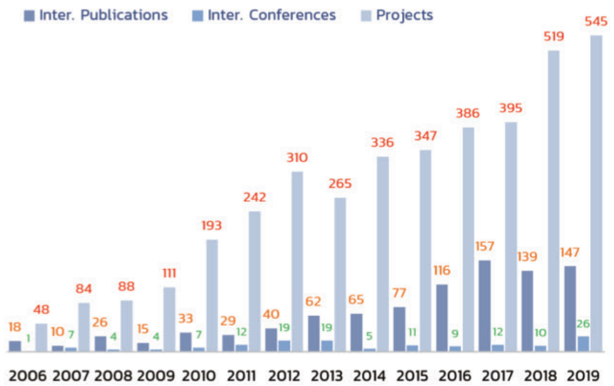


Figure 4: Numbers of proposal by fiscal year

In addition, workshops and training courses on special topics are arranged each year for both users and public who are interested in improving their experimental and analytical skills securing high quality data and publishable results [Figure 5].

Figure 5: ASEAN Synchrotron Science Camp

Industrial Section

SLRI has served Thai industrial sectors with analytical services ranging from routine characterization of product samples to conducting contract research projects utilizing synchrotron light and related technologies. The SLRI Business Development Division (BDD) aims to solve real problems, promote various forms of innovations, facilitate technology adaptation, and transfer established knowledge to the industrial sectors for self-sustainability. The BDD has provided services as follows:

(1) Synchrotron-based techniques service
(2) Research service (in term of agreement)
(3) Technical & engineering service
(4) Consultancy service
(5) Scientific instrument service
(6) Others (i.e., workshop, training, technology transfer etc.)

The service strategy of BDD has proven to be effective as the number of accepted projects has been continuously increased every year since 2010 [Figure 6]. For the last two years, the SLRI has served 35 applications submitted by research partners from 21 companies. The companies are well known as leading manufacturers of commodities and everyday products such as metal, cement, glass, rubber and polymer, electronic device, automotive parts, medicine, cosmetics, drug, and food. The most requested synchrotron-based techniques are X-ray absorption, scattering, fluorescence, and photoemission. Therefore, the industrial utilization of synchrotron radiation at SLRI facility clearly demonstrates the sustainable growing of Thailand's knowledge-based infrastructure and nation's demands for advanced analytical tools.

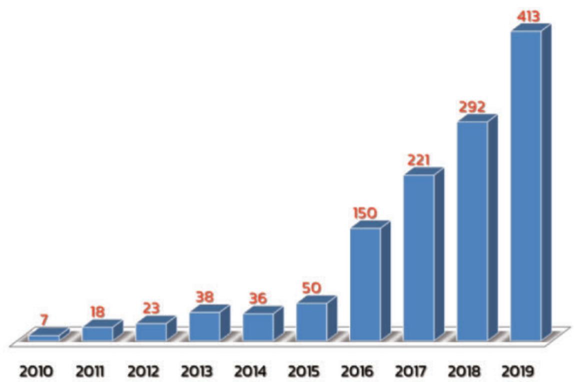


Figure 6: Numbers of industrial project by fiscal year

The Future of SPS II

A synchrotron light source is a crucial scientific infrastructure and has been recognized by developed countries as a powerful tool for advanced technologies and innovation. It has tremendous benefits for researches in medicine, agriculture, industry and other areas to support country development in various aspects such as economy, society, human capital, etc. The new synchrotron light source has electron beam energy at 3 GeV and circumference of 321.3 meters with cutting-edge technology called double triple bend achromat (DTBA) which will result in bright synchrotron light approximately 1 million times of the existing one produced from the current 1.2 GeV synchrotron light source. The new light source can accommodate up to 22 beamlines which can be applied for a variety of research applications. The location of new light source is agreed to be in the area of the Eastern Economic Corridor of Innovation (EECi), Rayong Province, Thailand, due to several factors: (1) geological stability, (2) transportation accessibility, (3) industrial estate locating nearby, (4) neighbouring scientific research institutes and universities in Eastern Economic Corridor (ECC) area, and (5) cooperation and joint venture with private sectors in response to government's Eastern Economic Corridor (EEC) development plan. This project will promote the large investment for economic growth and firmly and sustainably elevates country development due to the "Thailand 4.0" model.

Figure 7: Fourth-generation SPS II (3 GeV)

Professor Wing Commander Dr. Sarawut Sujitjorn, Chief Executive Officer of Synchrotron Light Research Institute (SLRI) mentioned that the SLRI Siam Photon Source-II (SPS-II) project is set up to build the 3 GeV synchrotron light source [Figure 7], the large research infrastructure of Thailand. It will advantage the country by creating jobs, careers, and developing skilled labors in construction, machines, designing, manufacturing parts and project operations. Once the construction has been completed, the light source can serve private sectors and increase economic value at least 6,000 million Bath a year. The new 3.0 GeV synchrotron light source can support varieties of research such as:

1. Medical science: to study structure of proteins, viruses and enzymes to find the mechanism of infection leading to development of new medicines, enhancing medical and pharmaceutical capabilities

2. Food and agriculture: to increase value product management, agricultural engineering process, food processing, quality improvement, safety of food through packaging in accordance with government plans for food and agricultural industry development

3. Advanced materials industry: to help analyzing the changes of material sample properties under different environments, to support research and development of construction material application such as new concrete formulas, metals and new composite materials

4. Environment: to support contamination analysis in more precise environment, to study link between plant diseases and molecules that the plant can absorb leading to finding ways to prevent disease in plants and reduce economic losses

5. Archeology: to study forensic archeology studies which will be a structural analysis at the atomic level in depth, both finding for sources as well as the simulation of 3D structures using synchrotron-based techniques in order to solve the missing ancient information and the production of new products for restoration

The Future of SPS II (continued)

In addition, the new 3 GeV synchrotron light source to be constructed at EECi, has a comprehensive safety management in all aspects, especially preventing radiation hazards from synchrotron production. There are also strict safety, health and environmental management systems complying with laws and international standards.

Radiation safety for the operation of the new 3 GeV synchrotron light source has begun with radiation evaluation from sources to properly design the shielding wall for particle accelerators tunnels, electron storage ring, beamline and end station. The computational simulation can determine specifications of shielding walls and evaluate their effectiveness prior to an actual construction. The radiation must be routinely measured during operation to certify safety validation. The amount of radiation must be controlled at minimal for radiation workers and related personnel in accordance to safety regulation of Thai laws and international standards of IAEA under strict control by the Office of Atoms for Peace.

To construct the new 3.0 GeV synchrotron light source at EECi [Figure 8], SLRI has already prepared an initial EIA report and the questionnaire for opinions from the residents in the Wang Chan Valley, Pa Yup, Muang, Rayong, to let them participate in the adequacy of preventive measures and to reduce environmental impacts from project development to residents in the surrounding area during the construction phase and project implementation phase as well.

Thus, Thailand will have 3 GeV synchrotron light source in the next 8 years, which is considered as a long-term development of the country. Scientific knowledge, research, technology, development and innovation are factors driving the country intensely. The use of scientific knowledge supports development of many new technologies and innovations and will never stop. It leads to solution of problems, cost reduction, reduction of imports from foreign countries and increment of the potential for the manufacturing, service and social sectors to focus on creating more value for the industry. These increase the competitiveness of the country with Thailand 4.0 model, link development of Thailand's economy with stability and sustainability. With such potential and readiness, it is an important step for Thailand to be a leading synchrotron research facility in the Asia-Pacific region in the near future, similarly to the roles of Australia, Japan, P.R. China, Taiwan, South Korea, Sweden, and other countries have played in their regions.

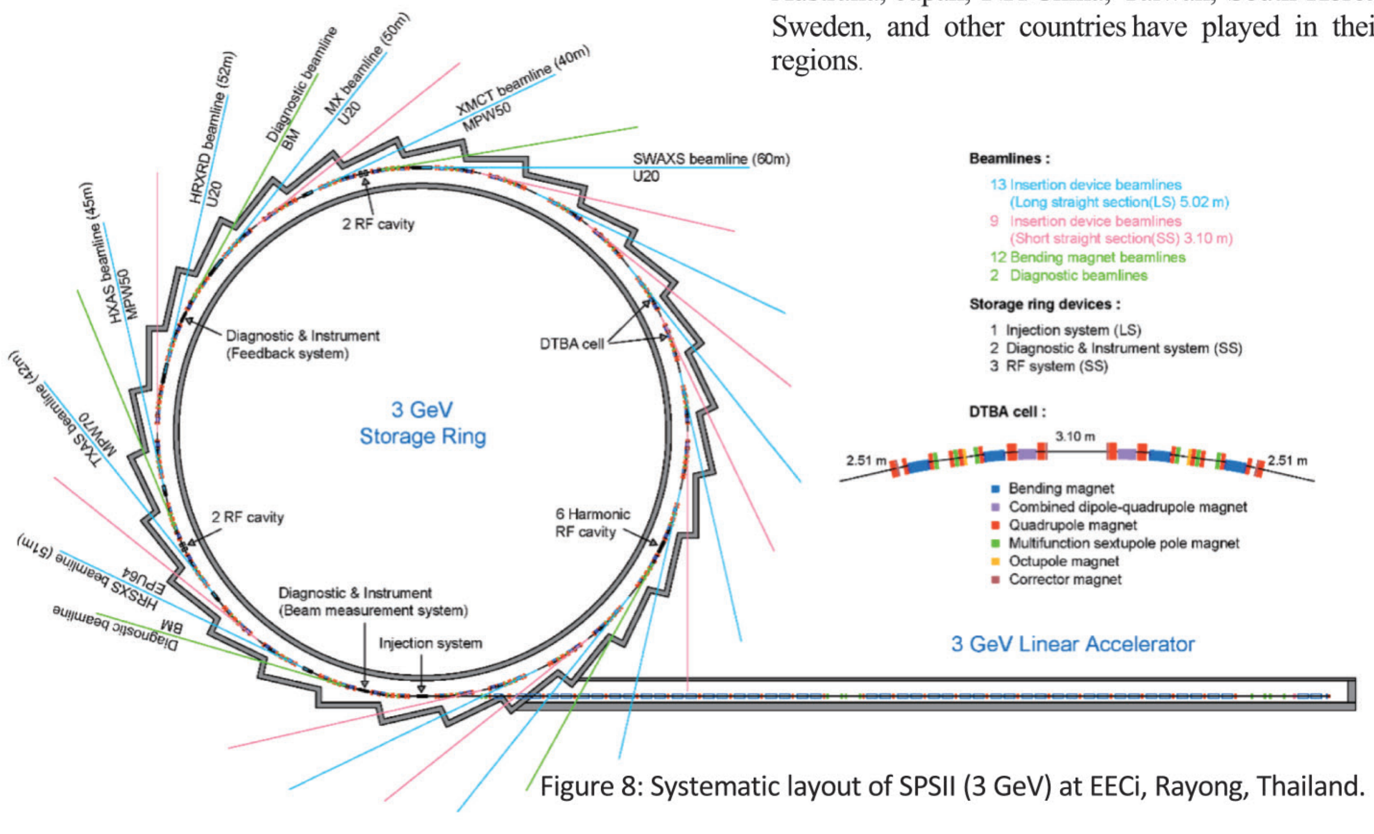
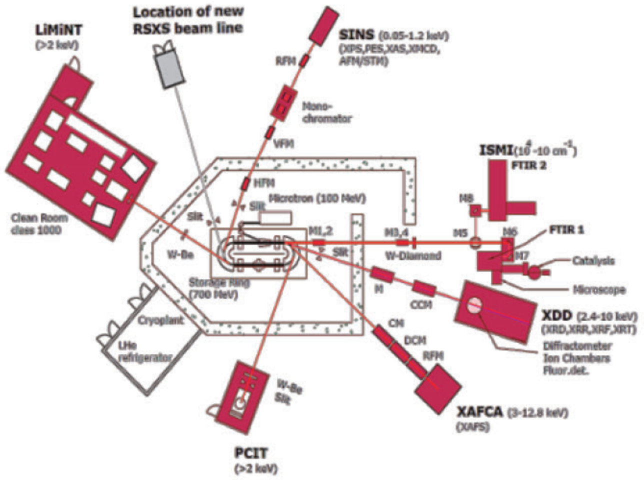


Figure 8: Systematic layout of SPSII (3 GeV) at EECi, Rayong, Thailand.

Singapore Synchrotron Light Source (SSLS)

General Information



Helios 2 and beamlines layout.

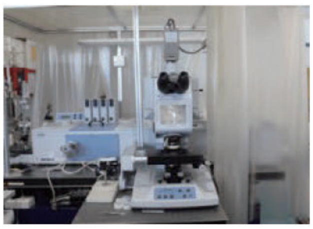
About us

The Singapore Synchrotron Light Source (SSLS) comprises a compact superconducting storage ring with 700 MeV electron energy and a 4.5 Tesla magnetic field to produce synchrotron radiation with characteristic photon energy of 1.47 keV and a characteristic wavelength of 0.845 nm. The useful X-ray spectrum extends from about 10 keV down to the far infrared at wave numbers less than 10 cm^{-1}.

Parameter	Unit	Value
Electron Energy	MeV	700
Magnetic Field	T	4.5
Characteristic photon energy	keV	1.47
Characteristic photon wavelength	nm	0.845
Current (typical)	mA	350
Circumference	m	10.8
Lifetime	h	>10
Emittance	µmrad	0.5
Source diameter horizontal	mm	1.45-0.58
Source diameter vertical	mm	0.33-0.38
Number of beam ports		20 + 1
Horizontal angular aperture of port	mrad	60

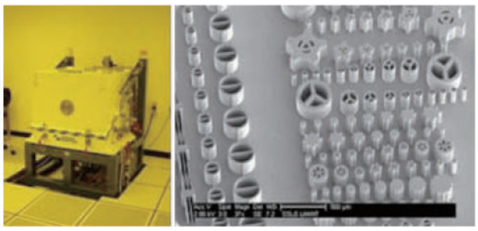
Beam lines

ISMI: Infrared Spectro/Microscopy provides a state-of-the-art Fourier Transform IR spectrometer and microscope to supply diffraction-limited spatial resolution to an ever-widening range of infrared spectroscopy experiments. The synchrotron-based source

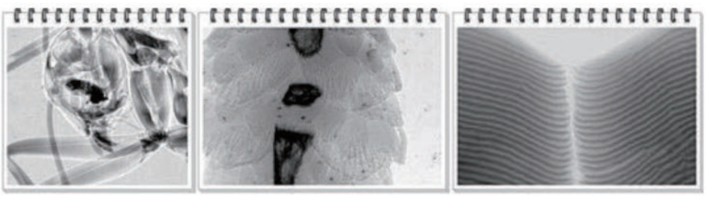


provides a versatile infrared source that covers a spectral range from 10000 to 10 cm^{-1} and has considerable brightness advantages over conventional (thermal) IR sources, enabling IR experiments with high resolution and studies of extremely small samples

LiMiNT: Lithography for Micro- and Nano-Technology offers X-ray lithography to the scientific and industrial community. The deep penetration of X-rays allows fabrication of microstructures with very high aspect ratios (LIGA technology).
Below: The Oxford Danfysik scanner in the LiMiNT cleanroom and 250-µm high SU-8 microstructures after X-ray lithography.



PCIT: Phase Contrast Imaging and Tomography features a white beam of hard X-rays with an energy range of about 4 to 12 keV. The X-rays are converted to visible photons by a scintillator and deflected by a mirror into a high-sensitivity CCD camera.

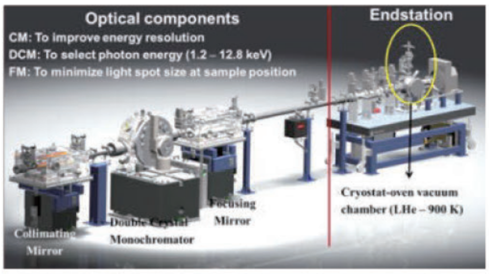


Singapore Synchrotron Light Source (SSLS)

Current Activities & Future Perspectives

SINS: Surface, Interface and Nanostructure Science provides synchrotron radiation for surface science experiments such as photoemission spectroscopy (PES), X-ray photoelectron diffraction (XPD), near-edge X-ray absorption spectroscopy (NEXAFS), photoemission electron microscopy (PEEM), and X-ray magnetic circular dichroism experiments (XMCD). The available photon energy range reaches from 50 eV to 1200 eV.

XAFCA: X-ray Absorption Fine structure for catalysis
This facility was set up by the Institute of Chemical & Engineering Sciences (ICES) to perform advanced X-ray absorption fine structure (XAFS) research on catalysis, materials science and related disciplines with Transmission XAFS and fluorescence XAFS. XAFCA provides a wide energy range from 1.2 to 12.8 keV, which covers the absorption edges of the main elements relevant to catalysis research.

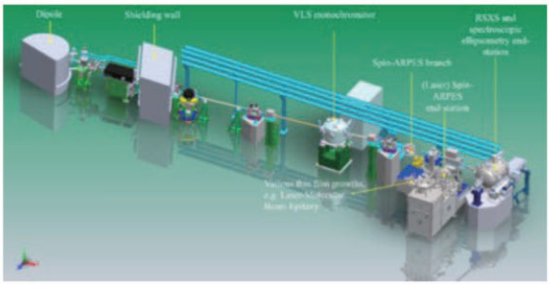


XDD: X-ray Diffraction and Demonstration
XDD was designed for general purpose diffractometry, fluorescence detection, and absorption spectroscopy. High-resolution diffraction is used for precise structure parameters, minute strain status, composition, thickness, surface/interface roughness, and texture/stress analysis.

Future Perspectives

We are in the process of commissioning two new facilities which will greatly enhance our ability to provide analytical services to users in Singapore and overseas.

SUV: The Soft X-ray – ultraviolet (SUV) beamline produces photons with selective polarization (i.e., linear and circular polarized light, covering the photon energy range from soft X-ray to UV). It will be used for various advanced optical, spectroscopy and scattering measurements and will feature the following experimental techniques and capabilities: resonant soft X-ray and magnetic scattering (RSXMS) on various samples, from ultrathin film, nanoparticle, to bulk.



- Spectroscopic ellipsometry and reflectivity from soft X-ray to ultraviolet
- UV-VUV photoluminescence
- Optical magnetic circular dichroism (OMCD)
- Near edge X-ray absorption spectroscopy (NEXAS)
- Soft X-ray magnetic circular dichroism (SXMCD)
- X-ray photoemission spectroscopy (XPS)
- Ultraviolet photoemission spectroscopy (UPS)
- (Laser) Spin- and Angular-resolved photoemission spectroscopy (Spin-ARPES)
- Thin film growth

EUV branch beamline:
EUV (extreme ultra violet) lithography is set to become the dominant lithographic process to define features in microelectronic devices, due to its ability to pattern feature sizes down to about 10 nm. Many EUV optical components need to operate in a reflection mode rather than a transmission mode, as the absorption is too high, requiring the development of high quality reflective surfaces, typically based on Bragg reflectors where one uses a multilayer of quarter wavelength layers to constructively reflect a single incident wavelength with high efficiency. Synchrotron radiation can deliver a high flux of photons of the desired wavelengths (tens of nanometers), corresponding to a required photon energy range of 70 to 110 eV. We are constructing a branch beam line on SINS to establish a facility capable of testing the reflectivity of the Bragg reflectors designed to operate in the EUV range.

THE AUSTRALIAN SYNCHROTRON

General Information

The Australian Synchrotron is part of the Australian Nuclear Science and Technology Organisation (ANSTO) and is a world-class research facility that uses accelerator technology to produce powerful beams of X-ray and infrared radiation. The facility harnesses that light so that researchers can study the structure, composition and behaviour of materials, on scales ranging from the atomic to the macroscopic. The Australian Synchrotron supports high-quality research outcomes, with applications in sectors from medicine and nanotechnology to manufacturing and mineral exploration. Our highly advanced techniques and passionate staff contribute directly and demonstrably to scientific advances and industrial innovations with benefits for all Australians.

The Australian Synchrotron is one of Australian's most important pieces of landmark scientific infrastructure.

140 staff supports 5000 hours of User Operations

10 Beamlines + 8 *Beamlines Under Construction*

7,700 Registered Users

1000 User Experiments per year

5,500 User Visits per year

4,840 Journal Publications from Users or Staff

~600 Journal publications per annum.

25% Journal Publications with Impact Factor > 7

2,300 Protein Structures in Protein Data Bank

1,300 Graduate Theses

CURRENT BEAMLINES:

IMBL– Imaging and Medical

IRM – Infrared Microspectroscopy

MX1 & MX2 – Macromolecular & Micro Crystallography

PD – Powder Diffraction

SAXS/WAXS– Small & Wide-Angle X-ray Scattering

SXRs – Soft X-ray Spectroscopy

THz/Far-IR – Terahertz/Far-Infrared

XAS– X-ray Absorption Spectroscopy

XFM – X-ray Fluorescence Microspectroscopy

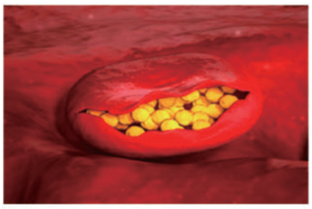
THE AUSTRALIAN SYNCHROTRON

Current Activities

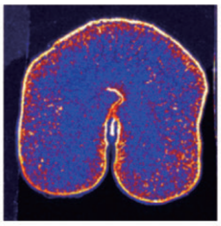
The Australian Synchrotron's sophisticated scientific techniques provide benefits for diverse scientific and industrial fields and purposes.

Health and wellbeing of society

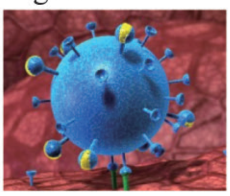
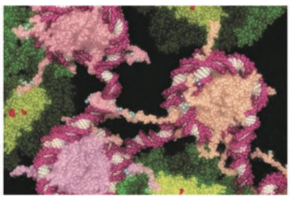
Biomedicine: Offering new, world-class diagnostic, imaging and therapeutic techniques and investigation of implants and biomimetic materials (such as artificial skin and organs), as well as conducting cell imaging, and high-throughput structural biology capabilities.

Food technology: Analysing the composition of ingredients, assessing the effectiveness of food processing and determining the nutritional impact of foods.




Life Sciences and pharmaceuticals: Understanding disease, fighting bacteria and viruses, and supporting agriculture. Analysing proteins, nucleic acids, bacteria and viruses that are fundamental to healthy biological function or disease; quality control monitoring, identification and assessment of the effectiveness of drug targets.

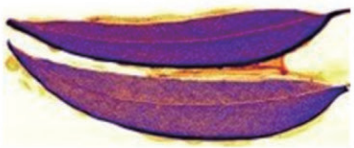



Cultural Heritage: Partnerships of art and science provide a new paradigm for imaging and understanding artworks and items of cultural heritage that have eluded conventional technologies.

Environment and Resources

Environmental technologies and services: Supporting environmental remediation and analysis of soil samples, the quality and composition of fresh and salt water, air and atmospheric samples, pollutants, toxins and contaminants.

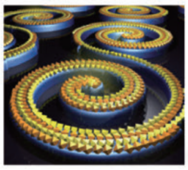

Mining and Minerals: Supporting all aspects of mineral exploration and processing. Development of fuel systems and fuel cell innovations.




Energy Technology: Unique characterisation ability in materials for batteries and in the hydrogen economy, including in situ charge and discharge monitoring of battery systems.

Economic Development

Manufacturing: Investigating the structure and characterisation of alloys, catalysts, fibres, textiles, adhesives, polymers, plastics, surfaces, interfaces and coatings and analysis of stresses and texture in engineered components.




Scientific instruments: Developing detector technologies, new analytical techniques, medical implants and drug delivery systems.

Defence: Enabling study of the atomic structure of materials, sensors and specialty alloys.

Advanced Materials: Alternative energy and carbon capture, hydrogen generation and storage, batteries and electronic devices, new materials with industrial applications.

Future Activities

The BRIGHT Program for New Beamlines

The Australian Synchrotron features ten world-class beamlines, covering a broad range of applications including health and biological sciences, earth and environmental sciences, advanced materials, engineering and manufacturing, energy and sustainability science, cultural heritage and archaeology as well as fundamental physics, chemistry and accelerator science.

Such is the value of the facility to Australia's science and innovation ecosystem, that each of the existing beamlines is oversubscribed. With constant advances in scientific methods, researchers and industry partners require access to a broader suite of techniques than those currently available.

Under the Commonwealth Government's substantial $520 million operating program for the facility, ANSTO has raised more than $95 million from 30 partner contributors for the design and installation of eight new beamlines as part of the BRIGHT Program.

From the funding secured to date, and in consultation with contributors, design and construction has commenced on eight BRIGHT beamlines. The Program will see the completion of two beamlines each year, with the first to commence operation in 2021.

The BR–GHT beamlines are:

Beamline	Source	Energy Range	Features
Micro-computed Tomography (MCT)	Bending magnet	8 – 40 keV	0.7 µm spatial resolution; 6 (V) x 40 (H) mm FoV; conventional and phase contrast; mono or pink beam
Medium Energy X-ray Absorption Spectroscopy (MEX1 and MEX2)	Bending magnet	1.7 –3.5 keV 3 – 13.6 keV	MEX2: 3(v) x 5(H) mm; EXAFS MEX1: 2(V) x 10(H) mm; EXAFS; 5 µm microprobe; crystal spectrometer; cryostat
Biological Small Angle X-ray Scattering (BioSAXS)	Superconducting in-vacuum undulator	8 – 15 keV	0.5 x 0.5 mm; Double Multilayer Mono; 0.0013 – 4.0 $Å^{-1}$ Q-range Highly automated sample changer; SEC-SAXS; in-vacuum camera
Advanced Diffraction and Scattering (ADS1 & ADS2)	Superconducting multipole wiggler	50 – 150 keV 45.3, 74.0, 85 keV	ADS1; 10 µm – 1 mm; mono & pink beam; mono & E-dispersive diffraction; imaging ADS-2; fixed mono diffraction
High Performance Macromolecular Crystallography (MX3)	In-vacuum undulator	11.5 – 14.5 keV	8.5 x 2 µm ; 4 x 10^{12} ph/s Double Multilayer Mono; Tray Screening; Serial Crystallography
X-ray Fluorescence Nanoprobe (Nanoprobe)	In-vacuum undulator	5 – 20 keV	60 – 400 nm spatial resolution; DMM: elemental mapping; DCM: XANES; Ptychography; and scanning diffraction

THE AUSTRALIAN SYNCHROTRON

Synchrotron Radiation for the Future of Humanity

User support as a pathway to leading research

- Enabling research through integrated user experience.
- Facility staff in a privileged position to combine user science drivers with unequalled insight into the infrastructure and undertake first and best in class research that delivers real-life benefits.
- Optimal management of this balance between user-driven and facility-driven science is a parameter that synchrotron facilities can use to be effective in delivering impact for the benefit of society.

Health and wellbeing of society through partnerships

Capability – Australian Synchrotron MX1 and MX2 beamlines are key partnership tools for understanding the molecular pathways of disease and developing new treatments and medicines – particular focus at MX2 on cancer.
Outputs – 2/3 of all Worldwide Protein Data Bank deposited protein structures from Australia and New Zealand are solved at the Australian Synchrotron.
Outcomes – the Walter and Eliza Hall Institute (WEHI) in Melbourne, along with AbbVie, Inc. and Genentech USA, Inc. in the United States used MX2 to develop a new drug, Venclexta™, now being used to treat Chronic Lymphocytic Leukaemia around the world. Royalty payments have returned hundreds of $millions to WEHI.
Partnerships – based in part on successful outcomes like Venclexta™, the Australian Cancer Research Foundation provided a $2 million AUD donation to the Australian Synchrotron, which with contributions from research partners has added state-of-the-art detector capability to the MX2 beamline – greatly increasing throughput for cancer research.
Capability – the Imaging and Medical Beamline (IMBL) delivers the widest synchrotron beam in the world providing a development pathway towards clinical imaging of human patients.
Partnerships – with research organisations for beamline, detector and measurement techniques to support phase-contrast imaging and X-ray Computed Tomography (CT) with emphasis on lung function and disease treatment, vascular studies, and tumour detection – particularly relating to breast cancer – as well as with researchers from Australia and Europe developing better understandings of the mechanisms relating to Microbeam Radiation Therapy for cancer treatment.

Societal Impact

At the Australian Synchrotron exploration of hidden paintings and indigenous art have received widespread attention, in addition to studies revealing hidden detail in documents left by early European explorers. Archaeological studies have rolled back the clock on the earliest occupation of the continent to more than 65,000 years ago.

The coverage afforded high profile cultural discoveries improves societal wellbeing through education. But synchrotron facilities play a leading and direct role in education of new generations of researchers, for instance over 1200 PhD theses from Australian Synchrotron data have been generated in the last decade of operations. The realisation of future plans will consolidate the reach and impact of graduate training. The formation of a Graduate Institute in partnership with research training organisations is increasing the numbers of students accessing the facility and increasing the training benefits from greater access to researchers and infrastructure.

The Graduate Institute is part of a larger Innovation Precinct being constructed by ANSTO. In a rapidly changing world, the challenge of solving technological and manufacturing problems of the future will require highly skilled trans-disciplinary teams which are not readily available to the start-up and SME community who make up most of this industry sector. The Innovation Precinct brings together scientific partners, and businesses to provide a unique environment with opportunities to embrace world class expertise, teaching, research and industry ready graduates. This environment allows integrated learning, collaborative research, student placement and technology incubation to flourish.

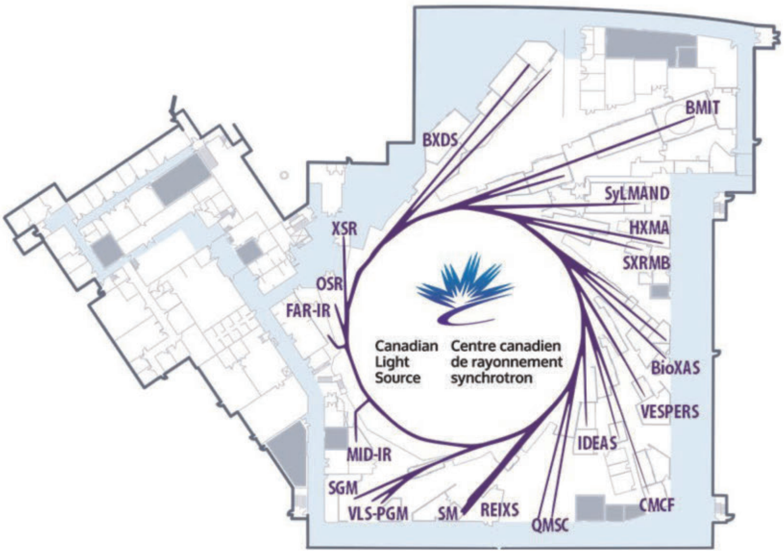
Canadian Light Source

General Information

The Canadian Light Source is a national research facility, producing the brightest light in Canada—millions of times brighter than even the sun. One of the largest science projects in our country's history, scientists from around the world use our light every year to conduct ground-breaking health, agricultural, environmental/clean technology and advanced materials research.

The CLS hosts more than 1,000 researchers annually from academic institutions, government, and industry and has enabled over 5,000 scientific publications/patents, with over 67,375 citations to date.

The Canada Foundation for Innovation, Natural Sciences and Engineering Research Council, National Research Council of Canada, Canadian Institutes of Health Research, the Government of Saskatchewan and the University of Saskatchewan fund our operations.



CLS in numbers (2018)

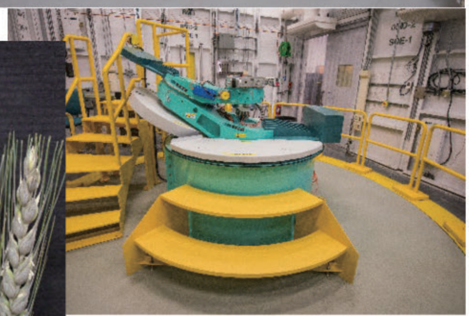
- 1,161 researchers
- 600 science publications
- Users from 15 countries
- Operating beamlines: 22
- Number of staff: 243
- 20 Canadian user research institutions and universities
- User operations started: 2005

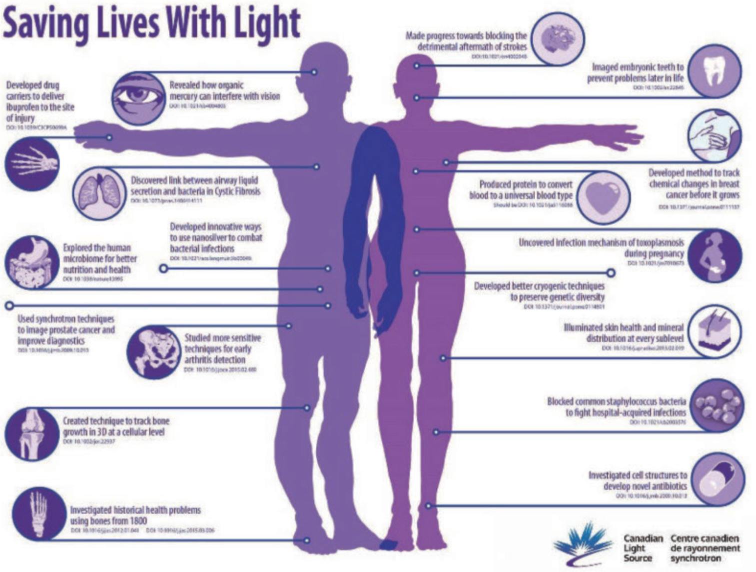
Canadian Light Source

Current Activities

The CLS has four strategic areas of research focus: health, agriculture, environment/clean technology and advanced materials

In health, CLS has seen tremendous progress in outstanding contributions to the field of structural biology. Entries to the Protein Data Bank (PDB), critical contributions to biological and pharmaceutical research, have now surpassed 1200. Much important work has been done uncovering mechanisms involved in many diseases, including Parkinson's disease, HIV-1, osteoporosis / osteoarthritis and bone remodeling, the route of lung infection in cystic fibrosis, cancer, multiple sclerosis, heart disease, blood types, new drug development, antibiotic resistance, malaria, stroke, and toxoplasmosis.

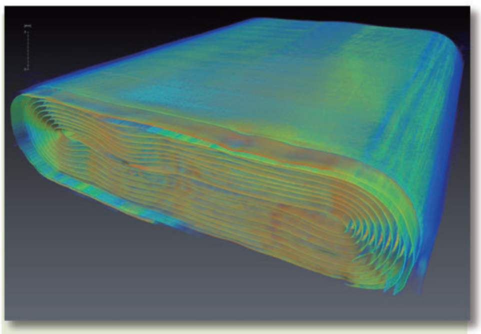




Advancements using CLS in agriculture include new insights in improved crop and plant development, fertilizers, drought and temperature resistance, and soil management.

In environmental science (including climate change), CLS has enabled advancements in mine remediation techniques, heavy oil extraction efficiencies, high efficiency catalysts for petroleum refinement, renewable resources, and energy storage, as well as remediation of contaminated groundwater and heavy metal contamination in soil and water.

In advanced materials, new insights and applications include high temperature superconductors, fuel cells, eco-composite materials, solar power, catalysts, microdevices, nanotubes, and new materials.



Application of μ-CT to study the internal stresses produced within a battery during cycling

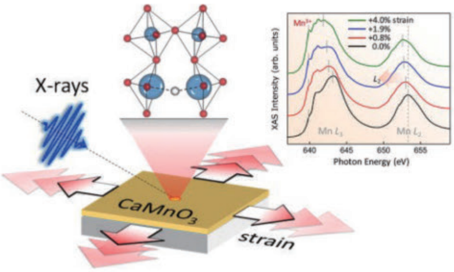
Advanced Light Source

General Information

The Advanced Light Source (ALS) is located in Berkeley, California. The original building, situated in the East Bay hills overlooking San Francisco Bay, was completed in 1942. Designed by Arthur Brown, Jr. (designer of the Coit Tower in San Francisco), the domed structure was built to house Berkeley Lab's namesake E. O. Lawrence's 184-inch cyclotron, an advanced version of his first cyclotron for which he received the Nobel Prize in Physics in 1939. Today, the expanded building houses the ALS, a third-generation synchrotron and national user facility that attracts scientists from around the world.

Scientific leadership

- world-class infrared to x-ray science
- world-leading soft x-ray science
- spectroscopy, scattering, and imaging techniques



ABOUT THE ACCELERATOR

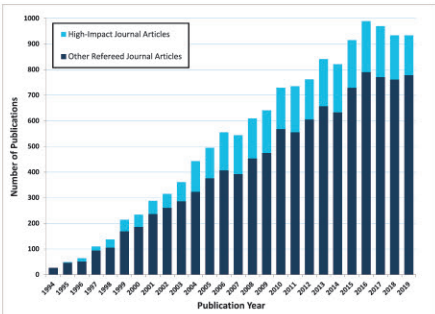
Number of electrons in each bunch	7 billion
Time between electron bunches	$2x10^{-9}$ sec
Size of the electron beam	~0.20mm x 0.01mm (the width of a human hair)
Distance electrons travel in the booster ring (in 0.45 sec)	135,000 km
Electron revolutions around the storage ring per second	1.5 million
Energy of electrons in the storage ring	1.9 GeV
Speed electrons travel at their highest velocity	299,792,447 meters/sec (that's 99.999996% the speed of light!)
Aluminum foil used per year	20,928 sq ft

Outstanding annual metrics

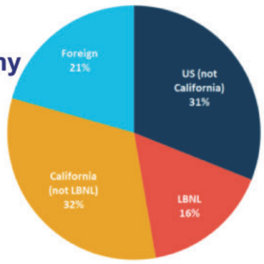
- 2300 users
- 950 scientific publications
- 5000 operating hours per year

26 years of growth

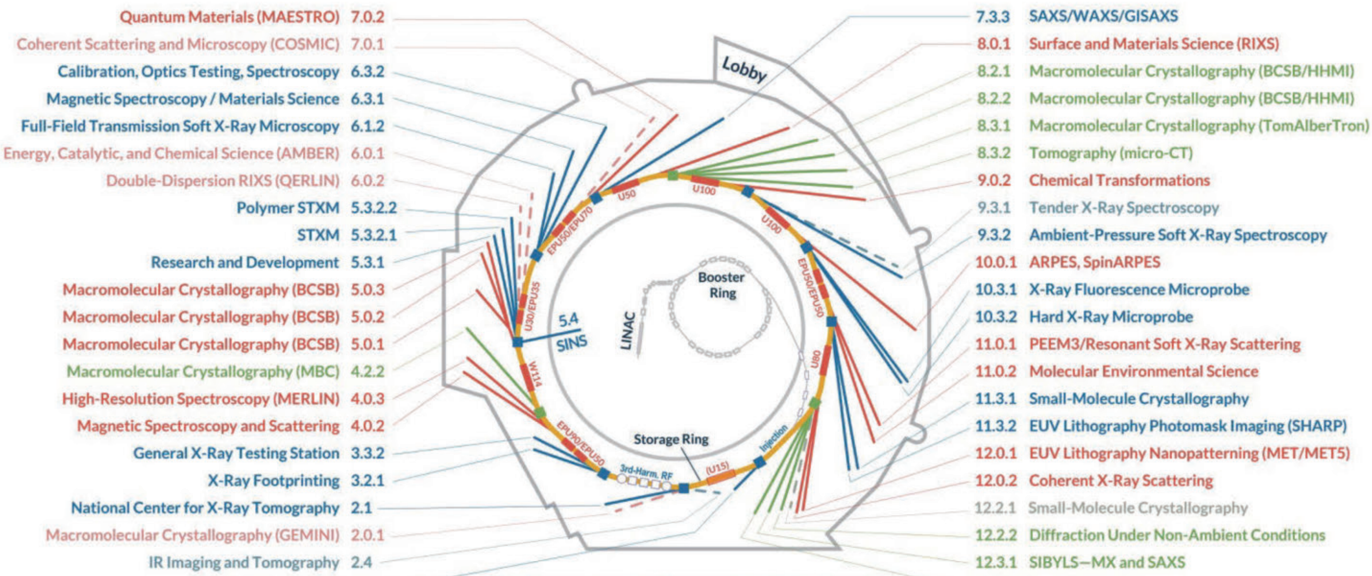
- 40 instrument beamlines
- planned ALS upgrade (ALS-U) project will enable light that is 100 times brighter
- continual upgrades of science capabilities



Users by Geography



ALS Operates 40 Instrument Beamlines for Users

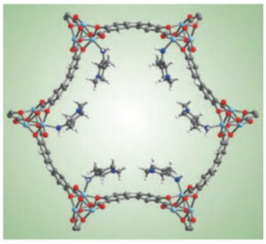


8.2017

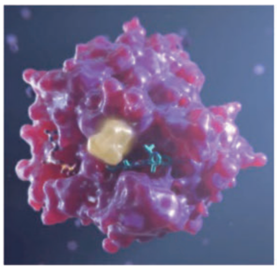
Advanced Light Source

Science Highlights

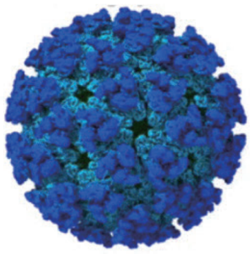
Water Improves Material's Ability to Capture CO_2. With the help of the ALS, researchers from UC Berkeley and ExxonMobil fine-tuned a material to capture CO_2 in the presence of water. The parties have applied for a patent on the material, which was developed for use on the relatively humid flue gases emitted by certain natural gas power plants, a cleaner-burning alternative to coal.



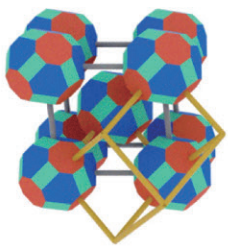
ALS Reveals Vulnerability in Cancer-Causing Protein. A promising anticancer drug, AMG 510, was developed by Amgen Inc. with the help of novel structural insights gained from protein structures solved at the ALS. AMG 510, which is currently in phase II clinical trials for efficacy, targets tumors caused by mutations in the KRAS protein, one of the most common causes of cancer.



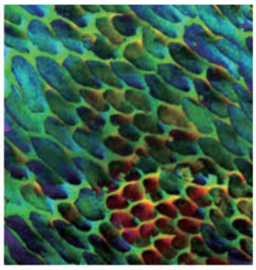
Molecular Handle Enables Viral Attack on Joint Cells. A collaboration of university and industry researchers used x-ray crystallography to investigate how the chikungunya virus, which can cause debilitating joint pain, engages a receptor protein found on the surfaces of joint cells. The work provides a path forward in the fight against a family of viruses that can result in acute and chronic arthritis.



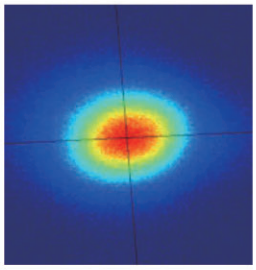
The Choreography of Quantum Dot Fusion. X-ray scattering experiments helped reveal how nanosized crystals ("quantum dots") self-assemble and fuse to form "supercrystals" with potentially useful electronic properties. The findings provide new insight into the fabrication of high-performance, low-cost electronic materials for photovoltaic and photon-sensing applications.



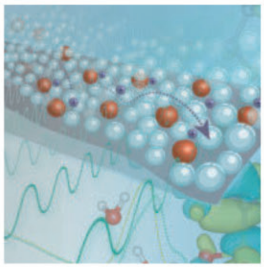
Crystal Misorientation Toughens Human Tooth Enamel. Researchers discovered that, in the nanoscale structure of human enamel (the hard outer layer of teeth), slight crystal misorientations serve as a natural toughening mechanism. The results help explain how human enamel can last a lifetime and provides insight into strategies for designing similarly tough bio-inspired synthetic materials.



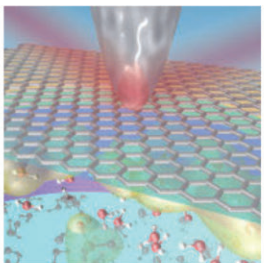
Machine Learning Helps Stabilize Synchrotron Light. Researchers showed that machine learning can predict noisy fluctuations in the size of beams generated by synchrotron light sources and correct them before they occur. The work solves a decades-old problem and will allow researchers to fully exploit the smaller beams made possible by recent advances in light source technology.



Multimodal Study of Ion-Conducting Membranes. Using multiple x-ray characterization tools, researchers showed how chemical and structural changes improve the performance of a novel ion-conducting polymer (ionomer) membrane from 3M Company. The work provides insight into factors impacting the proton conductivity of ionomers used for fuel cells and the production of hydrogen fuel.



Infrared Nanospectroscopy at Graphene–Liquid Interfaces. Researchers developed a new infrared approach to probing the first few molecular layers of a liquid in contact with a graphene electrode under operating conditions. The work offers a new way to study the interfaces that are key to understanding batteries, corrosion, and other bio- and electrochemical phenomena.



To learn more, go to als.lbl.gov

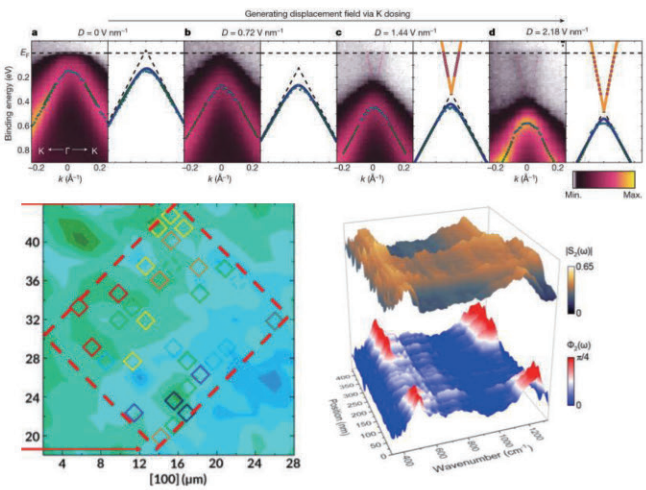
Advanced Light Source

Science Thrust Areas

Thrust areas (TA) have been identified that encompass critical growth areas in x-ray science and instrumentation. The TAs are organized around cross-cutting themes and include scientists from the ALS and collaborating LBNL divisions. Members of the TAs collaboratively develop the science and instrumentation strategy for their area and reach out to the user community to launch initiatives that result in new beamline projects.

1. Quantum Materials Research and Discovery

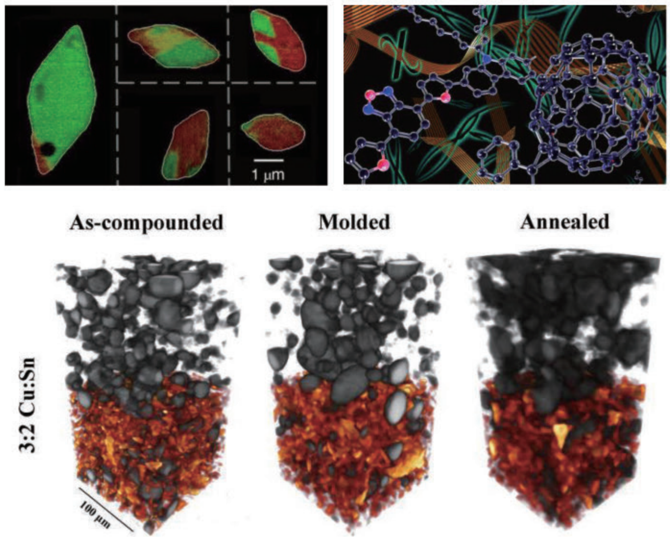
The discovery, synthesis, and characterization of novel functional quantum materials is the central theme of this TA. Soft x-ray spectroscopy, scattering, and microscopy tools have played a major role in the discovery and understanding of the exotic and fascinating physics of many new classes of spin, quantum, and topological materials over the past few decades: oxide and pnictide superconductors, manganites exhibiting colossal magnetoresistance, graphene and other 2D materials, topological insulators and semimetals, and multiferroics, to name just a few examples. After a spectacular century- long endeavor to understand quantum materials, starting with the discovery of low-Tc superconductivity in 1911, these efforts will continue to provide the foundation for new electronic and information processing technologies. These developments will depend on an ever-improving understanding of the electronic and magnetic structure of materials gained from the world's best characterization tools.



Top: Changes in the Na_3Bi band structure measured using angle-resolved photoemission spectroscopy (ARPES) at four different levels of K dosing, indicating an electric-field-induced switching of the 2D topological phase [J. Collins et al., Nature 564, 3090 (2018)]. Bottom left: Strain map of a composite multiferroic material imaged using microdiffraction [R. Lo Conte et al., Nano Lett. 18, 1952 (2018)]. Bottom right: Synchrotron infrared nanospectroscopy (SINS) maps of patterned SiO_2 demonstrating sensitivity to Si–O stretching and bending modes [O. Khatib et al., ACS Photonics 5, 2773 (2018)].

2. Complex Materials and Interfaces

The Complex Materials and Interfaces Thrust Area seeks to advance our understanding of functional, heterogeneous materials by quantifying their properties across a wide range of length and time scales using scattering, spectroscopic x-ray probes, and various imaging techniques.



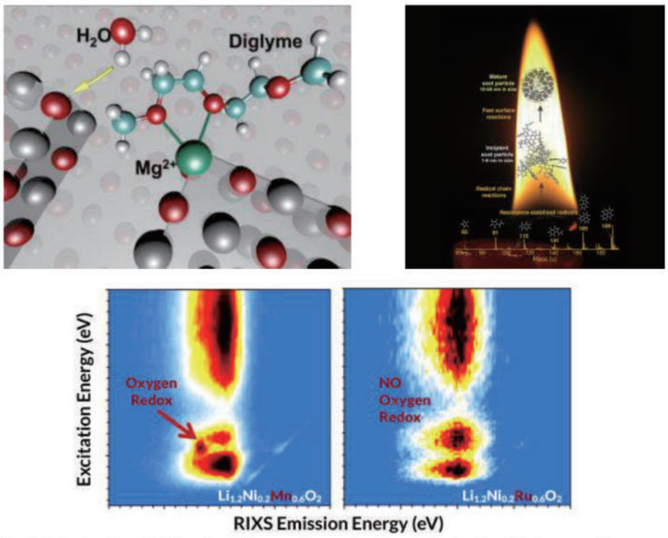
Top left: STXM images of the lithium distribution in Li_xFePO_4 battery particles at different electrolyte exposures [Y. Li et al., Nat. Mater. 17, 915 (2018)]. Top right: Artistic interpretation of an organic solar-cell mixture containing a blend of polymers and fullerenes, which was studied by resonant x-ray scattering [L. Ye et al., Nat. Mater. 17, 253 (2018)]. Bottom: Microtomography experiments at the ALS show the distribution of copper (red) and tin (gray) as a function of different processing conditions in conductive plastics. [Q. Yang et al., J. Appl. Polym. Sci. 134, 43 (2017)].

High-priority goals are the development of instrumentation for the following:

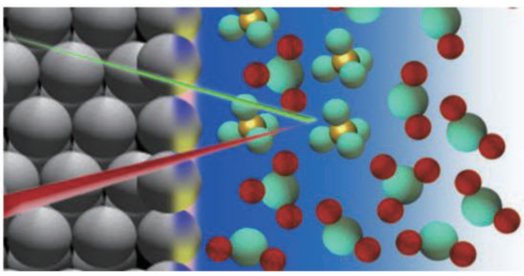
- Spectromicroscopic and tomographic measurements of functional, heterogeneous materials from the nanometer to millimeter length scales under operando conditions with chemical, magnetic, and morphological sensitivity.
- Microscopy and resonant scattering methods that utilize the tender x-ray energy range to study biological, geological, and energy materials containing elements such as Na, Mg, Al, Si, P, S, Ca, and Fe, among many others.
- Resonant and coherent resonant scattering (such as XPCS) studies of chemical and physical heterogeneity and dynamic processes in soft and hard matter, solid/liquid interphase systems, and membranes, using resonant scattering probes in the soft to tender x-ray range and small- and wide-angle x-ray scattering (SAXS/WAXS) in the hard x-ray range.

3. Chemical Transformations

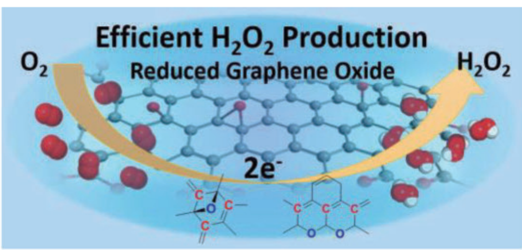
The Chemical Transformations Thrust Area focuses on studying the kinetics, energetics, and products of chemical reactions and transformations in diverse environments, ranging from ultrahigh vacuum (UHV) to ambient and even higher pressures, in the presence of liquid and solid interfaces and homogeneous and heterogeneous catalysts. X-rays can penetrate chemical reactors, liquids, and gas-phase environments, and provide very specific chemical and molecular information about the catalysts, reactants, and products participating in a chemical reaction.



Top left: A molecular model shows the initial state of battery chemistry that leads to instability in a test cell featuring a magnesium anode. [Y. Yu et al., Chem. Mater. 29, 8504 (2017)]. Top right: VUV mass spectrometry was used to identify fast chemical reactions in flames and soot particles. [K.O. Johansson et al., Science 361, 997 (2018)]. Bottom: Full-range mapping of RIXS (mRIXS) reveals the novel oxygen states in various energy systems involving unconventional and critical oxygen states. [J. Xu et al., Nat. Commun. 9, 947 (2018)].



The efficient production of hydrogen peroxide (H2O2) from oxygen (O2) by a graphene oxide catalyst was studied by x-ray absorption spectroscopy. [H.W. Kim et al., Nat. Catal. 1, 282 (2018)].

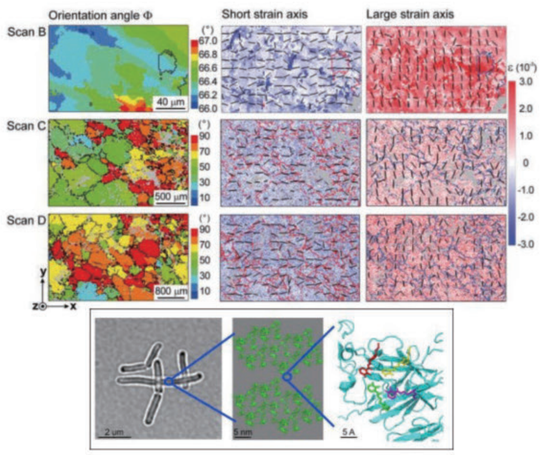


Operando x-ray absorption spectroscopy (XAS) detects the hidden "fingerprints" of various chemical species that collect just above the surface of a platinum electrode immersed in sulfuric acid to demonstrate the molecular structure of the platinum-sulfuric acid interface. [C.H. Wu et al., J. Am. Chem. Soc. 140, 16237 (2018)].

4. Earth, Environmental, and Biological Systems

Many of the beamlines relevant to the Earth, Environmental, and Biological Systems Thrust Area benefit from close collaborations with external entities. The very successful ALS macromolecular biology and biological imaging beamlines are operated by Participating Research Teams (PRTs), and the ALS coordinates its strategic planning closely with the LBNL Biosciences Area, which includes the Berkeley Center for Structural Biology (BCSB) and the Berkeley Synchrotron Infrared Structural Biology (BSISB) Imaging Program. The macromolecular crystallography PRTs consist primarily of pharmaceutical companies from across the U.S., as well as various academic institutions and the Howard Hughes Medical Institute (HHMI). ALS scientists also closely collaborate with researchers in the LBNL Earth and Environmental Sciences Area and external consortia, such as the Consortium for Materials Properties Research in Earth Sciences (COMPRES), via Approved Programs (APs).

A common thread running through most of the cutting-edge research activities in the Earth, Environmental, and Biological Systems Thrust Area is a move from static postmortem studies to time-resolved and/or in situ/operando/in vivo studies. The high penetration capabilities of hard x-rays and to some extent IR light (with diamond windows) makes these two probes central to these developments. The expansion of such studies to soft and tender x-ray experiments is also of central interest for this TA.



Top: Maps derived from Laue microdiffraction, displaying orientation (first column) and strain tensors (second and third columns) of deformed rocks from Belgium [K. Chen et al., Geophys. Res. Lett. 43, 6178 (2016)]. Bottom: Imaging on the micron scale of biological materials such as microbes can be accomplished with IR and microscopy techniques, with additional spectroscopic information to yield chemical information, while structural information on the nanometer length scale can be obtained with solution scattering methods, and structure at atomic length scales can be obtained with crystallography or x-ray footprinting. Shown in this figure is Geobacillus stearothermophilus (left), the layer of proteins coating the surface of the microbe (middle), and the atomic structure of a single surface-layer protein with chemical chelator molecules attached (right). [Baranova et al., Nature 487, 119 (2012)].

SLAC National Accelerator Laboratory

General Information

SLAC National Accelerator Laboratory operates major X-ray user facilities that are open to scientists from all over the world. Researchers compete for a chance to use our sophisticated equipment, which no single company or university could afford to build or operate alone.

- SLAC's **Stanford Synchrotron Radiation Lightsource** started the tradition in 1972. It was the first large X-ray facility to open its doors to outside researchers, and upgrades keep it on the cutting edge of science.
- SLAC's **Linac Coherent Light Source**, open since 2009, is the world's first hard X-ray free-electron laser. An upgrade now underway will greatly increase its average brightness and pulse rate.

SLAC by Numbers

- 1,600 staff, with 350 postdoctoral researchers and graduate students.

- 2,900 scientists use our cutting-edge facilities each year.

- More than 700 scientific papers are published each year based on SLAC research.

-4 Nobel prizes have been awarded for research at SLAC.

- At 3,073.72 meters (1.9 miles) long, our linear accelerator is one of the longest buildings on Earth.

- Electrons zip down that linear accelerator at 669,600,000 mph – 99.9999999 percent of the speed of light.

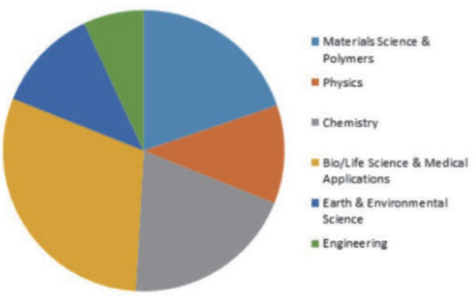
- 325 universities and research institutes use our resources, and 40 companies use our X-ray facilities for research aimed at developing medicines and other products.

SSRL-Stanford Synchrotron Radiation Lightsource

SSRL produces extremely bright X-ray light for probing our world at the atomic and molecular level. More than 1,700 scientists from all over the world use it each year for research that spurs advances in energy production, environmental cleanup, nanotechnology, new materials and medicine.

SSRL Facts:

- 150 staff members
- 1,700 scientists conducted experiments in 2018
- 16,500 refereed publications since 1974
- 5,004 operating hours in 2018
- 33 experimental stations



LCLS-Linac Coherent Light Source

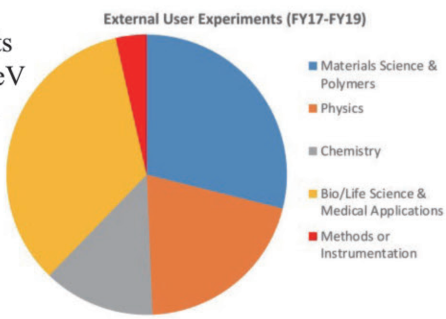
Once the scene of major discoveries in particle physics, SLAC's 2-mile-long linear accelerator now generates X-rays for LCLS, the world's first hard X-ray free-electron laser.

Like a high-speed camera with an incredibly bright flash, LCLS takes X-ray snapshots of atoms and molecules at work, revealing fundamental processes in materials, technology and living things.

The LCLS-II upgrade is adding a second X-ray laser beam that's 10,000 times brighter, on average, and increases the laser's firing rate to up to 1 million pulses per second.

LCLS Facts:

- 3,000 scientists have conducted experiments at LCLS
- 1,450 peer-reviewed publications since 2009
- 326 staff run the facility
- 8 experimental instruments
- Accelerator energy: 15 GeV
- Pulse duration: 0.2-200 fs
- Length: 4 km
- X-ray energy: 250 eV-25,000 eV



SLAC National Accelerator Laboratory

Current Activities

SSRL-Stanford Synchrotron Radiation Lightsource

Building Better Batteries

Scientists around the world are racing to develop cheaper, sturdier, more efficient batteries for electric cars, cell phones, laptops and other devices. At SSRL they can test new battery materials and components in realistic operating conditions, observing split-second chemical changes as the battery charges and discharges.

Saving Lives

Pharmaceutical companies use SSRL beamlines to find potential drugs that fit snugly into targets in the cell. Research here contributed to the development of Vemurafenib, a treatment for late-stage or inoperable melanoma, and Oseltamivir, a widely used antiviral drug marketed as Tamiflu, and identified shape changes in an Ebola virus protein that could help combat that disease.

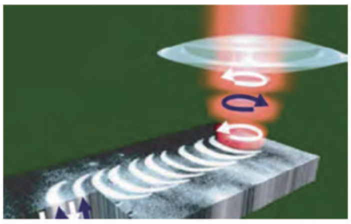
Improving Solar Cells

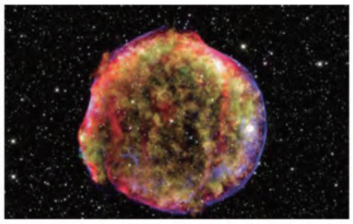
By packing molecules closer together, scientists have developed a semiconductor material that is among the speediest yet. This material—and the innovative process used to manufacture it—may significantly improve the efficiency and cost of organic solar cells used to turn the sun's rays into usable energy.

Spurring New Technology

Our partnerships with industry spur technical advances that would otherwise not have been possible. This leads to job creation and gives advanced technologies a foothold in the commercial market.

LCLS-Linac Coherent Light Source





Catching Photosynthesis in the Act

Photosynthesis is one of the most important chemical reactions on Earth, yet most aspects are not fundamentally understood. With LCLS, researchers can directly observe natural processes that convert sunlight into useable energy.

Revealing Life's Secrets

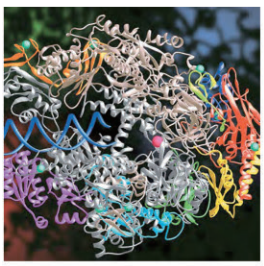
Scientists are using LCLS to determine the structures of proteins from tiny nanocrystals. This unique capability opens the door to studying tens of thousands of important biological structures that were out of reach before, including proteins involved in disease and its treatment.

Developing Future Electronics

Experiments at LCLS are exploring new ways to design and control the magnetic and electronic properties of an important class of electronic materials with ultrashort pulses of light. This could ultimately lead to extremely fast, low-energy computer memory chips or data-switching devices.

Studying Matter in Extreme Conditions

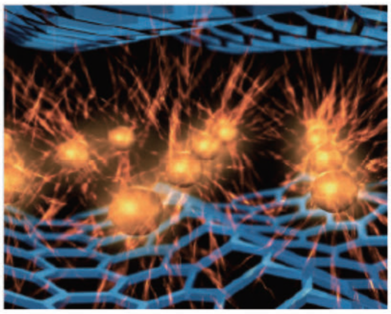
LCLS gives scientists tools for investigating extremely hot, dense matter that exists at the centers of stars and giant planets. These experiments help researchers explore how materials respond to stress, design new materials with enhanced properties, and study the science that underpins the nuclear fusion process that powers the sun.



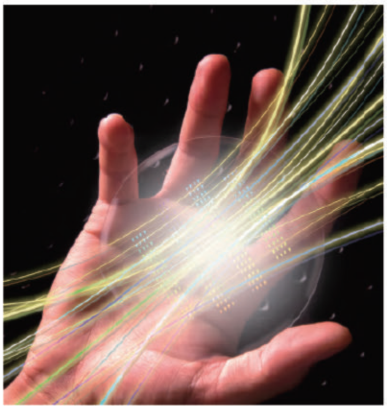
SLAC National Accelerator Laboratory

Future Perspective

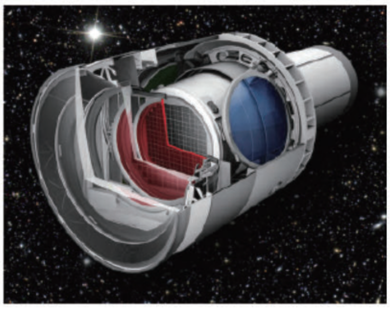
At SLAC, we explore how the universe works at the biggest, smallest and fastest scales and invent powerful tools used by scientists around the globe. Our areas of exploration include:



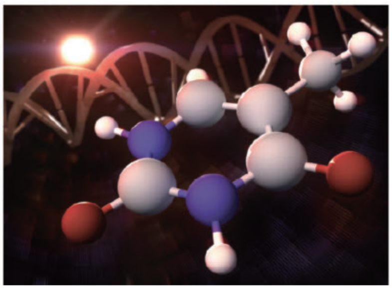
- **Designing new materials for alternative energy**
  Scientists at SLAC are focusing on the atomic-scale design of materials for energy production and storage. Examples of SLAC research critical to future energy technologies are the use of catalysts to create cleaner fuels and develop sustainable processes for producing chemicals and materials, and making materials for better, more efficient batteries for energy storage.



- **Developing smaller and more powerful accelerators**
  SLAC is at the forefront of experiments aimed at improving the power and efficiency of particle accelerators used in basic research, medicine, industry and other areas important to society. By inducing electrons to "surf" on waves of plasma, researchers have accelerated these particles to 1,000 times greater energies over a given distance than ever before.



- **Pursuing dark matter and dark energy**
  SLAC is leading the construction of the world's biggest digital camera for Vera C. Rubin Observatory, which will undertake the widest and deepest sky survey ever, dramatically increasing our knowledge of dark matter, dark energy, galaxy formation and potentially hazardous asteroids. It's also fabricating the super-cooled crystals at the heart of the next-generation Super Cryogenic Dark Matter Search experiment.

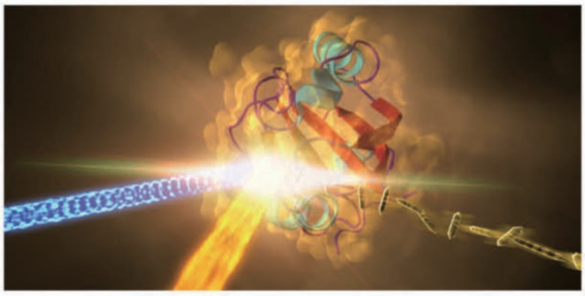


- **Making molecular movies**
  The ultrafast, ultrabright X-rays of SLAC's LCLS are giving researchers an unprecedented view of the atomic world. Advanced instrumentation and expertise at the facility enabled the creation of the world's first "molecular movies," revealing chemistry behind the processes of life.

SLAC NATIONAL ACCELERATOR LABORATORY

Fundamental Science, Practical Benefits

SLAC pushes the frontiers of human knowledge and drives discoveries that benefit humankind. We invent the tools and provide the facilities that make those discoveries possible and share them with scientists from all over the world.



Above: A protein from a photosynthetic bacterium changes shape in response to laser light. SLAC X-ray studies reveal how proteins work in our bodies and in nature. (Greg Stewart/SLAC) Left: SLAC's 2-mile-long linear accelerator (Brad Plummer/SLAC)

When scientists delve into basic details of the world around us, practical benefits often follow. This is true of research at SLAC.

In chemistry, "molecular movies" made with our X-ray laser are capturing all the tiny steps of chemical reactions for the first time. This new understanding will help improve reactions that give us fuels, fertilizers and a host of other products.

In biology, X-rays reveal how proteins – one of the key molecules of life – function in our bodies and in nature. This research has contributed to the development of medications for melanoma, flu and HIV and is aiding the fight against Ebola, high blood pressure and other ills.

SLAC studies of exotic materials with quirky traits could have a profound impact on society, although it may be far in the future. Meanwhile, scientists use our X-ray beams for experiments to improve materials for computer chips, jet planes, refinery operations and "smart windows" that automatically adjust the amount of light coming in, to name a few.

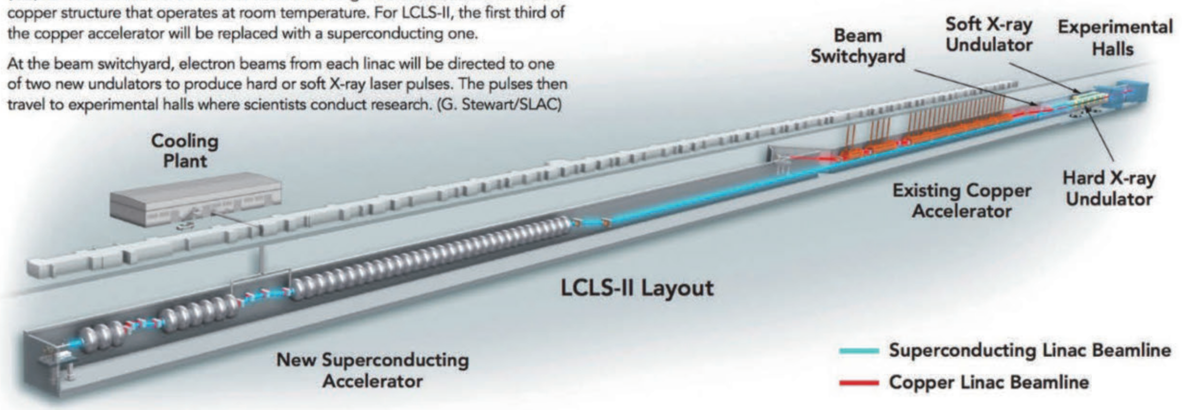
Many threads of SLAC research come together in the quest for clean, sustainable energy sources. We study how plants make energy from sunlight with an eye to doing the same, and customize chemical reactions for generating clean fuels. Our specialized X-ray equipment allows scientists to watch batteries, solar cells and fuel cells in operation, a crucial step in improving how they work.

Boosting the Power of SLAC's Premier X-Ray Laser

Our 2-mile-long particle accelerator is the lab's backbone. Once the scene of major discoveries in particle physics, today it generates the world's brightest X-rays for our revolutionary X-ray laser, the Linac Coherent Light Source (LCLS). LCLS is getting a major upgrade that will significantly boost its power and capacity, allowing it to deliver X-ray laser beams that are 10,000 times brighter with pulses that arrive up to a million times per second. LCLS-II will further sharpen our view of how nature works at the atomic scale and help advance transformative technologies of the future, including novel electronics, life-saving drugs and innovative energy solutions.

Below: The future LCLS-II X-ray laser (blue) is shown alongside the existing LCLS (red). LCLS uses the last third of SLAC's 2-mile-long linear accelerator – a hollow copper structure that operates at room temperature. For LCLS-II, the first third of the copper accelerator will be replaced with a superconducting one.

At the beam switchyard, electron beams from each linac will be directed to one of two new undulators to produce hard or soft X-ray laser pulses. The pulses then travel to experimental halls where scientists conduct research. (G. Stewart/SLAC)

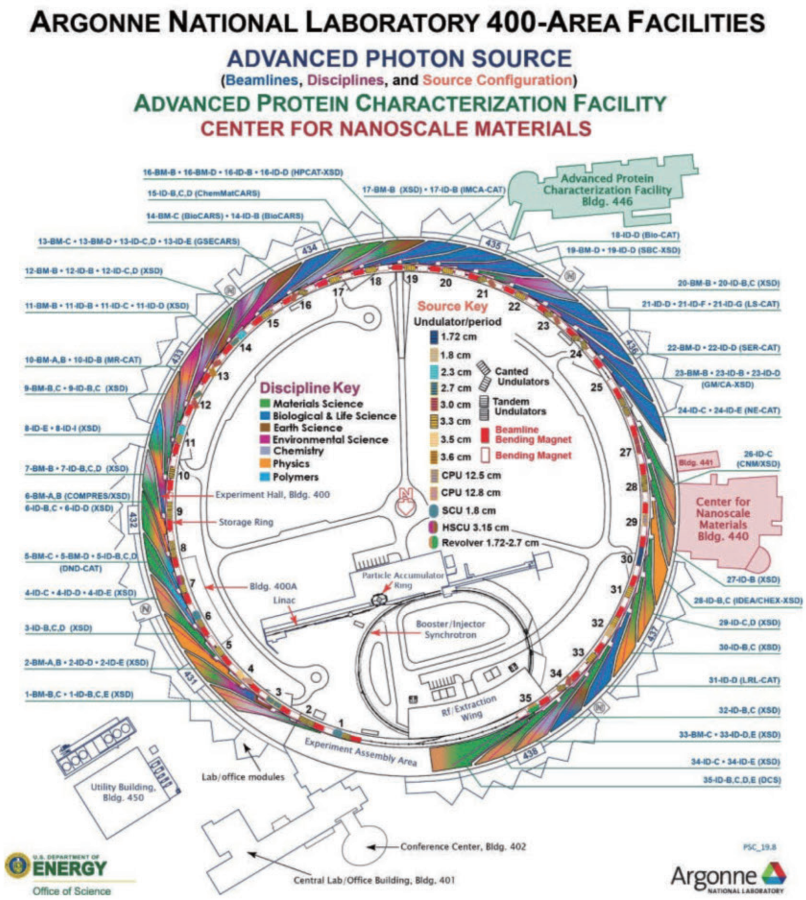


The Advanced Photon Source

General Information

The Advanced Photon Source (APS), which was completed in 1995, with user operations starting in 1996, is supported by the U.S. Department of Energy Office of Science-Basic Energy Sciences, and serves one of the largest scientific user communities in the U.S. Located at Argonne National Laboratory near Chicago, IL, the APS provides high-brightness, high-energy (hard) x-ray beams to users from all 50 states, the District of Columbia, Puerto Rico, and more than 30 nations, who annually publish more than 2100 papers contributing to knowledge and innovation in materials science, physics, the biology and life sciences, chemistry, and the geological and environmental sciences. At the heart of the APS is a high-energy, 7-GeV electron accelerator that feeds a 1.1-km-circumference storage ring where undulators and bending magnets deliver x-rays to 68 independently operating beamlines. The APS is embarked on a multibend achromat upgrade, with first light for the up-graded facility in approximately 2023.

- 7-GeV, 100-mA, top-up operations
  - 35 ID sectors, 46 undulator beamlines, 22 bending magnet beamlines
  - Effective emittance: 3.1 nm-rad
  - Vertical emittance: 0.040 nm-rad, 1.5% coupling
  - Three fill modes: 24-bunch top-up mode (65% of time, ~9 h lifetime); hybrid top-up mode (15% of time, ~6 h lifetime); 324-bunch mode that does not require top-up (~60-h lifetime)
- 5000 user hrs of operation scheduled each year with ~98% user-beam delivery
- Operations budget: $138 M U.S. in FY19
- Over 5400 unique users in FY19
- ~2700 new research proposals submitted in 2019
- ~ 60% acceptance rate for beam-time requests
- World leader in solving protein structures: over 24,000 structures determined at APS deposited in the Protein Data Bank
- User affiliations (FY16):
  - 63% from U.S. universities,
  - 16% from U.S. federally-funded Labs
  - 3% from U.S. industry
  - 12% from foreign institutions
  - 6% other

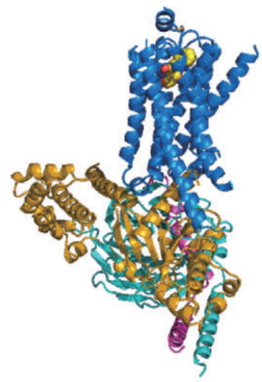


The Advanced Photon Source

Current Activities

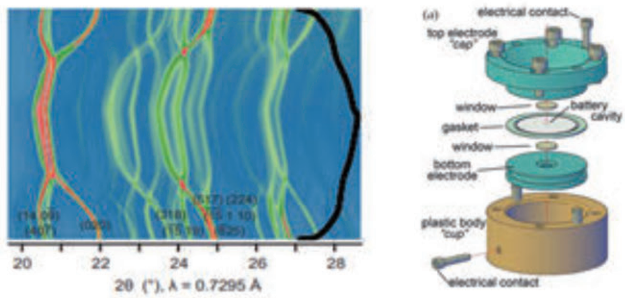
The high-energy, high-brightness, highly-penetrating x-ray beams from the Advanced Photon Source (APS) give researchers access to a powerful, versatile tool that is ideal for studies that help us solve the challenges of our world, from developing new forms of energy to sustaining technological and economic innovation to pushing back against the ravages of disease.

The APS has a very strong user base working in the field of life sciences: All three recipients of the 2009 Nobel Prize in Chemistry published papers on their award-winning work on ribosomes based on data collected at the APS (and other synchrotron radiation facilities). In 2012, the Nobel Prize in Chemistry was awarded for work on G-protein-coupled receptors, thanks in large part to research performed at the APS. Venclexta® (venetoclax) developed by AbbVie for treating leukemia, recently joined the growing list of important new pharmaceuticals derived from research at the APS.



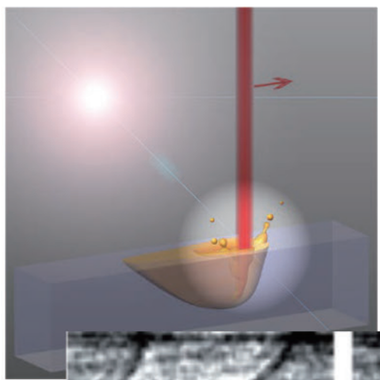
The structure of the G-protein-coupled receptor.

Energy research, from better batteries to renewable energy sources, is another important area of research for APS users. The penetrating power of high-energy x-rays enables studies of the structure, charge state, and morphology of a material under realistic operating conditions and observation of how these change during cycling. For instance, changes in the crystalline phases and local atomic structure of a battery electrode material can be determined using x-ray diffraction and pair distribution function measurements and a specially designed electrochemical cell. Such studies can help improve the resiliency of electrodes to enable faster-charging, longer-lasting batteries for use in high-power applications such as electric cars.

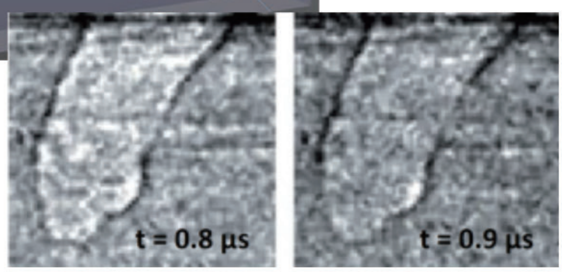


In operando *x-ray diffraction of the crystalline phase in a $Nb_{16}W_5O_{55}$ electrode during the charging (delithiation) and discharging (lithiation) cycling (left) in a specially designed electrochemical cell (right).*

Research on additive manufacturing materials and processes has been a rapidly developing area of study at the APS. This includes both *ex situ* characterization of the crystalline phases, microstructure (including pores and voids), and thermomechanical properties, of the manufactured products, as well as *in situ* observations of during the fusion of the constituent materials themselves. The APS has developed unique high-speed x-ray imaging and diffraction capabilities to observe *in operando* powder bed laser-fusion processes in order to optimize the operating parameters for 3D manufacturing. These studies are essential for validating such materials for use in industrial applications such as aerospace and nuclear technologies.



Rendering of synchrotron study of laser-induced spattering. Image: Qilin Guo (Missouri University of Science and Technology) and Cang Zhao (Argonne National Laboratory)



High-speed x-ray imaging of the binder jetting additive manufacturing process. A closer look at the binder droplet is also displayed on the side of each image. The frame rate is 20,000 frames per second.

The Advanced Photon Source

Future Perspective

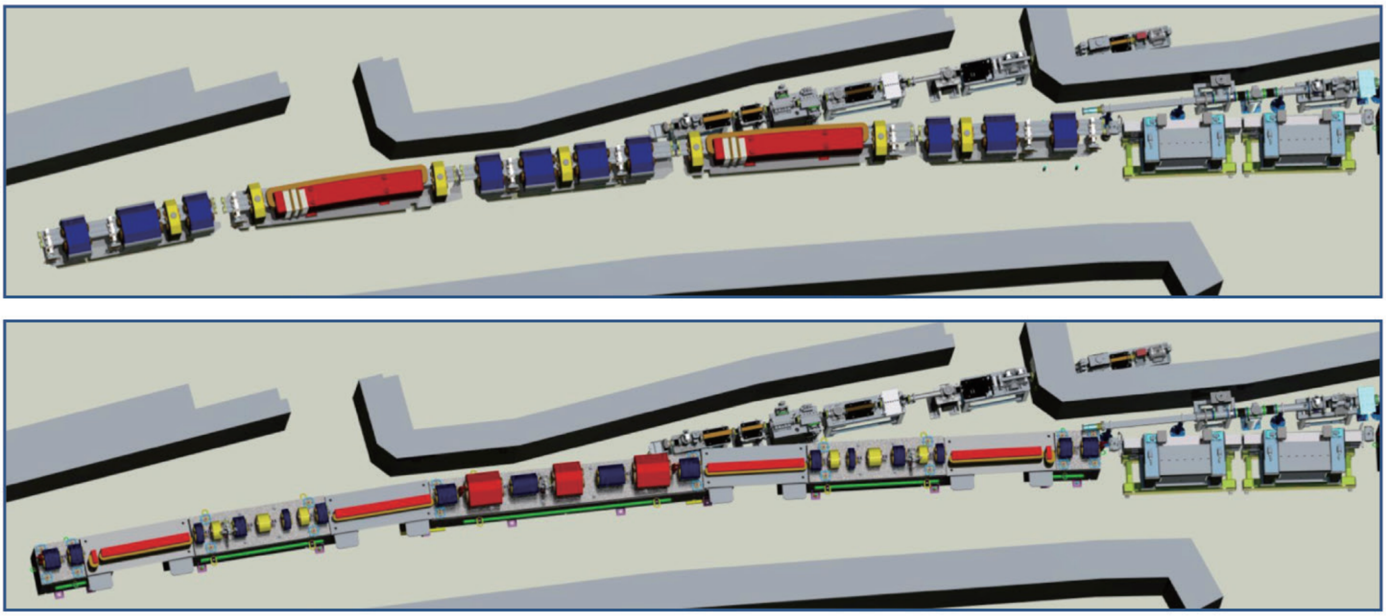
A quarter-century ago, the United States invested $500 M U.S. in building the U.S. Department of Energy Office of Science's Advanced Photon Source (APS) at Argonne National Laboratory. The APS has provided an exceptional source of high-energy x-rays, expanding researchers' concepts of what was possible and invigorating the synchrotron x-ray science community.

Now, the proposed Advanced Photon Source Upgrade (APS-U) will be a brightest source of hard x-rays from a storage ring, transforming our ability to understand and manipulate matter at the nanoscale. With this powerful, versatile tool, researchers will be able to observe individual atoms moving and interacting – in real time – deep inside real samples, biological organisms, and complex engineered systems.

The APS-U will build a high-brightness, hard x-ray storage ring with:

- A multi-bend achromat lattice and high stability to provide the first U.S. fourth-generation storage ring x-ray source
- Next-generation undulators to produce the highest x-ray brightness
- Advanced beamlines to fully exploit the high-brightness source

The APS-U will deliver a generational leap in storage ring performance: the 500x increase in brightness for hard x-rays will enable revolutionary capabilities such as coherent diffractive imaging and ptychography, delivering >10^4 enhancement for correlation spectroscopy techniques, and efficiently focusing x-rays to nanometer-size spots.



The APS storage ring double-bend lattice today (top) and the future 7-bend lattice (bottom.

	APS Present	APS-U/High Brightness	APS-U/48-Bunch Mode
Energy/Current	7 GeV / 100 mA	6 GeV / 200 mA	6 GeV / 200 mA
Effective Emittance	3113 pm	42 pm	32 pm
Brightness* @ 20 keV	1	528	250
Flux Density*# @ 20 keV	1	12.8	10.6

*Brightness relative to present APS performance

#Flux density relative to present APS performance, through a 0.5-mm x 0.5-mm aperture @ 30 m

The Advanced Photon Source

Synchrotron Radiation for the Future of Humanity

The upgrade of the U.S. Department of Energy Office of Science's Advanced Photon Source (APS) at Argonne National Laboratory creates a synchrotron x-ray light source optimized via a multi-bend achromat (MBA) lattice. This facility exceeds the capabilities of today's synchrotrons by two-to-three orders of magnitude in brightness and coherent flux in the hard x-ray range of >20 keV, enabling a transformational range of new probes for structure, properties, and functionality of matter.

Since the early discoveries of Laue, Compton, Moseley, and the Braggs, insights derived from x-ray scattering, diffraction, and spectroscopy have been essential in solving challenging scientific problems. X-ray techniques have transformed our scientific understanding of the world around us and have been central to our ability to create new materials and chemistries with the potential for enormous impacts in engineered structures, pharmaceuticals, electronics, and a host of other applications. The scientific advances enabled by x-ray techniques have been tremendous and continuous, driven both by discoveries of new fundamental ways to derive insight from the interaction of x-rays with matter, and by the evolution of light sources themselves.

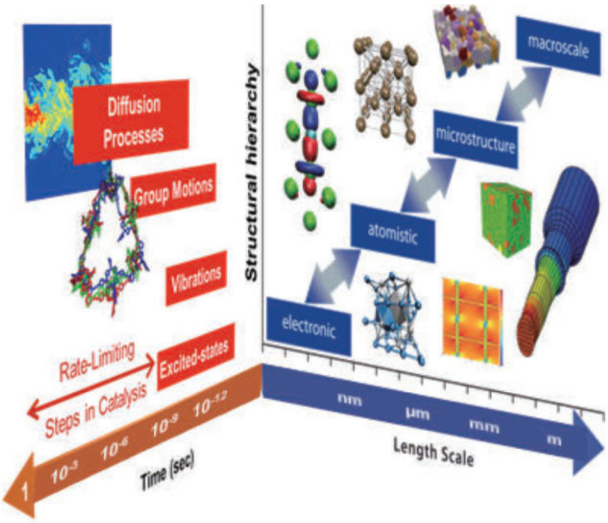
As the generation of x-rays has evolved, from the earliest sealed tubes to electron storage rings and free-electron lasers, each new source has yielded transformational levels of insight.

Now, the new scientific and engineering challenges that face us dovetail with critical societal issues, providing an opportunity for the APS Upgrade to continue the rich international tradition of "science in the public interest."

These opportunities include:

Interrogating chemical synthesis processes to develop new systems for catalysis and filtration; for instance, finding new zeolites

Exploring the pathways by which new materials are grown from solutions and from the vapor phase, to create new materials for photovoltaics, information processing, and information storage



Determining the neural connectome, and understanding the inner workings of cellular machinery

Developing an understanding of mesoscale order to produce materials with better mechanical properties for transportation and national security

Gaining an understanding of contamination transport in the natural environment

Mapping trace-metal flows in the environment that underpin certain aspects of ecosystem behavior and, ultimately, climate

Exploring systems at ultrahigh pressures for understanding the interior of the Earth and of exoplanets

These questions require new tools to image heterogeneity across length scales and time scales, to explore non-equilibrium structures and processes and non-stationary phenomena, and to unravel transport in complex systems and observe synthesis in action. A highly multiplexed, continuous source of highly energy-tunable, extremely stable, bright, and coherent hard x-rays such as the APS Upgrade, with an MBA lattice producing x-rays that approach the diffraction limit and a full suite of new and invigorated beamlines, provides the capabilities to realize these objectives.

Cornell High Energy Synchrotron Source (CHESS)

General Information

CHESS, the Cornell High Energy Synchrotron Source, is a high-intensity X-ray source which provides users state-of-the-art synchrotron radiation facilities for research in physics, chemistry, biology, environmental sciences and materials science. The National Science Foundation supports the Center for High-Energy X-ray Sciences at CHESS and operates beamlines optimized for the structural characterization of quantum materials, structural metals and biological systems, as well as X-ray spectroscopy of systems ranging from enzymes to energy materials. The National Institute of Health and New York State jointly support X-ray facilities for macromolecular crystallography and small angle scattering to understand the structure and function of the building blocks of life. The Materials Solutions Network at CHESS funded by the Air Force Research Lab provides dedicated access to X-ray beamlines for Air Force and other Department of Defense materials researchers enabling breakthroughs in materials and designs for national defense applications.

CHESS by the numbers

Storage Ring Parameters: 6 GeV; 50-200 mA positron beam in top-off operation; 768 meters circumference.

Operations Budget: US$22M in FY2020 from the National Science Foundation, the National Institutes of Health, New York State, and the Air Force Research Lab.

User Operations: Approx. 3600 hours of user operation annually; 7 beamlines in operation in 2020 (6 undulator sources, 1 wiggler source).

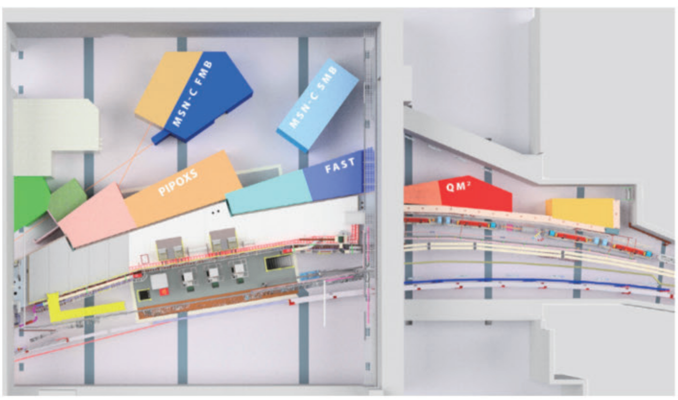
User Demographics: Over 1000 visiting researchers annually, half of which are early career scientists, postdoctoral researchers and graduate students; Approximately 280 unique experimental projects supported each year from among twice to three times as many proposals; 150 publications/year in refereed journals.

Recent Facility Upgrades

In October 2019, CHESS resumed user operations after a one-year shut down for a major upgrade project, known as CHESS-U, which establishes CHESS as one of the world's leading X-ray sources. The upgrade, which was funded by New York State, involved reconfiguring and optimizing the synchrotron storage ring for the production of intense high-energy X-rays and the concurrent upgrade of the X-ray experimental capabilities to exploit the redesign of the storage ring. An increase in flux and energy of the X-ray beams was achieved by increasing both the energy of the stored positron beam (from 5.3 GeV to 6.0 GeV) and the positron current (from 100 mA to 200 mA). Moreover, the emittance was considerably reduced, resulting in smaller and more collimated X-ray beams. These enhanced capabilities place CHESS as one of only five high-energy, third-generation synchrotron sources in the world. The high-energy X-ray beams at CHESS-U penetrate deep into samples, enabling the study of bulk materials, while the high-flux enables the study of weak signals. The upgrade thus has equipped CHESS for the study of diverse systems, ranging from the in situ characterization of structural materials and catalysts to structural studies of quantum materials as well as high-pressure biological processes. Parallel with the technical upgrade, CHESS has overhauled its funding structure.

No longer solely funded by the National Science Foundation (NSF), CHESS has transitioned to a model in which the funding is distributed across multiple partners, including the NSF, National Institutes of Health (NIH), US Air Force Research Laboratory (AFRL) and New York State. A new user facility funded by the NSF, i.e. the Center for High-Energy X-ray Sciences (CHEXS) at CHESS, provides beamlines for high-photon energy studies in biological sciences, engineering and materials research. AFRL has funded a new facility with beamlines for the study of structural metals and soft, functional materials, while the NIH-funded macromolecular X-ray science facility, with additional support from New York State, is now operated in partnership with CHEXS.

The new scientific capabilities and the diversification of funding are reflected in the wider communities of researchers who benefit from CHESS. Moreover, CHESS continues its practice of supporting and training new users, developing X-ray technologies and supporting high energy world-class X-ray studies.



Overview of part of the CHESS experimental floor in January 2020 showing five of the seven beamlines.

Cornell High Energy Synchrotron Source (CHESS)

Current Activities

Center for High-Energy X-ray Sciences at CHESS

The National Science Foundation (NSF) supports the Center for High-Energy X-ray Sciences (CHEXS) at CHESS and operates beamlines optimized for the characterization of various materials, as well as X-ray spectroscopy of systems ranging from enzymes to energy materials:

The *Q-Mapping for Quantum Materials (QM^2) beamline* is a facility for characterization of quantum materials in reciprocal space, using resonant and non-resonant scattering over a wide range of X-ray energies. The *Forming and Shaping Technology (FAST) beamline*, is capable of rapid (millisecond and below) high-energy X-ray measurements to study manufacturing processes such as laser welding and rapid quenching. The *High Pressure Biology (HPBio) beamlines* are devoted to monitoring the structure of the building blocks of life at the molecular level under high pressure. The *Photon-In, Photon-Out X-ray Spectroscopy* (*PIPOXS) beamline* is optimized for spectroscopic studies of valence electronic states in systems ranging from catalysts to enzymes. CHEXS also funds an X-ray Technology R&D program that enables research to advance X-ray science and technology developing novel X-ray optics, detectors and insertion device concepts.

Materials Solutions Network at CHESS

The Materials Solutions Network at CHESS (MSN-C) provides dedicated access to X-ray beamlines for Air Force and other Department of Defense materials researchers. MSN-C focuses on using techniques like high energy X-ray diffraction (HEXD) to determine how atomic structure and materials function – and failure – correlate.

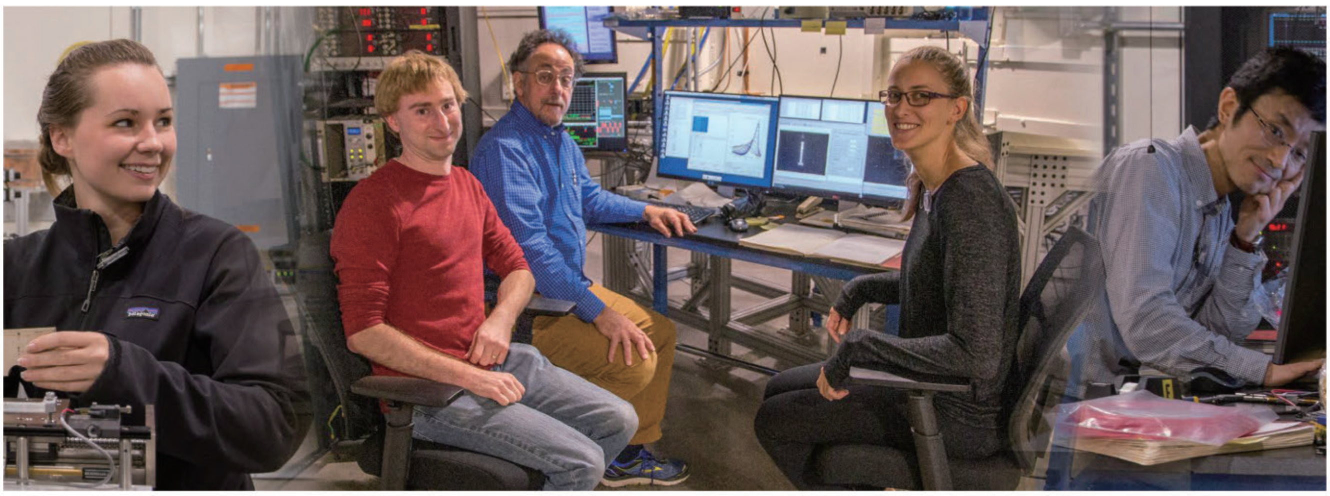
For example, the *Structural Materials Beamline (SMB)* allows measuring how each individual crystal grain within a metal evolves over hundreds of strain cycles. It is possible to mimic the conditions experienced by a titanium blade in a jet engine where a crack initiated at the micron scale eventually leads to the failure of the entire blade. At the *Functional Materials Beamline (FMB),* small and wide angle scattering methods are used to monitor the internal structure and alignment of fibers and molecules in soft materials produced in real time using 3D printing.

Macromolecular X-ray Science at CHESS

The National Institutes of Health and the state of New York jointly support X-ray facilities for Macromolecular X-ray science at CHESS (MacCHESS). The crystallography and small angle scattering beamlines are optimized to characterize the structure and with that function of macromolecules. CHESS has made rapid progress in developing room temperature or serial crystallography (SC), which involves taking a series of diffraction patterns scanning across microcrystals deposited on a support substrate or chip raster scanned through the X-ray beam or alternatively across a few larger crystals. The ability to "outrun" most radiation damage avoids the need for sample cooling and its artifacts, allowing studies of molecular machines at work at room temperature.

Together with CHEXS, MacCHESS operates the high pressure MX and SAXS beamlines described above.

Regular macromolecular crystallography as well as biological small angle X-ray solution scattering with automated sample loading and remote data collection are supported by MacCHESS as well.



Cornell High Energy Synchrotron Source (CHESS)

Future Activities

The CHESS strategic planning focusses on continuing to develop novel experimental techniques and technology using high energy, high flux X-ray beams to address modern and emerging scientific and engineering challenges.

High-energy X-rays (20-150keV) have a wavelength short enough that diffraction can determine the distance between atoms and energy well above electron binding energies, minimizing photoelectric absorption and enhancing penetration. These characteristics are key requirements for in-situ and operando studies of materials at the microscopic and macroscopic level. The recent CHESS upgrade enables new scientific capabilities at CHESS including enhanced micro-spectroscopy for life sciences, improved time-resolved X-ray diffraction as well as fundamental studies into strongly correlated materials:

Imaging critical life-cycle functions in plants

Over the last decade, synchrotron-based X-ray-fluorescence-based imaging techniques have emerged among the most direct, flexible, and powerful means of visualizing the elemental distribution within plants. This power arises from the ability to directly, simultaneously, and quantitatively image the concentrations of multiple elements down to the parts-per-million scale, in both 2D and 3D, in unprepared and even hydrated and live samples, and to assess chemical speciation. When paired with the tools of modern molecular genetics, this imaging capability provides an unprecedented opportunity to bridge the genotype-to-phenotype gap and assign functions to genes involved in mineral nutrient homeostasis in plants. A CHESS X-ray-fluorescence-based imaging beamline will discover the mechanisms by which plants absorb, control, and exploit metal ions to perform critical life-functions, from the sub-cellular regime to the whole-organism scale.

Sub-microsecond X-ray studies of materials under dynamic conditions

Many opportunities exist for time-resolved studies with high-photon energy synchrotron beams. The flexible bunch structure of the CHESS storage ring allows varying the delay between 100ps X-ray pulses generated by the positron bunches between 2ns and ~2.5µs. This provides an ideal tool to study materials dynamics in a wide range of systems such as structural transformations and defect propagation below the surface of a material initiated by external stimuli such as mechanical indentation or current pulses. Moreover, monitoring chemical reactions with dynamic X-ray absorption spectroscopy allows probing valence states e.g. of catalysis with “built-in” element-specificity.

Science with X-rays at the high magnetic field frontier

X-rays can uniquely address fundamental and yet unresolved questions about the nature of quantum systems, engineered materials and biological relevant macromolecules in high magnetic fields. Since facilities to enable this science are presently lacking, CHESS proposes to build a dedicated world-class high-energy X-ray beamline that will feature a custom low-temperature superconducting magnet generating continuous fields as high as 20 Tesla. The beamline will be designed to accommodate even higher fields from future magnets as new magnet technology becomes available.

Educating for the Future

Internationally, it is becoming harder and harder for students (undergraduate, graduate) to actively get "behind the shield wall". However, CHESS will continue to welcome students to actively participate in the design and assembly of novel experiments. This approach educates and – hopefully excites – a new generation of synchrotron scientists who will greatly impact the world of physics, biology, environmental sciences and materials research.

Science Highlights

Twisting the Helix: Salt Dependence of Conformations of RNA Duplexes

Ribonucleic acid (RNA) is a macromolecule essential in various biological roles in coding, decoding, regulation and expression of genes. Its biological functions depend critically on its structure and flexibility. To date, no consistent picture has been obtained that describes the range of conformations assumed by RNA duplexes. Here, Cornell researchers used X-ray scattering at CHESS to quantify these variations. Their results quantify the substantial and solution-dependent deviations of double-stranded (ds) RNA duplexes from the assumed canonical A-form conformation. *J. Phys. Chem.* B **123**, 9773 (2019).

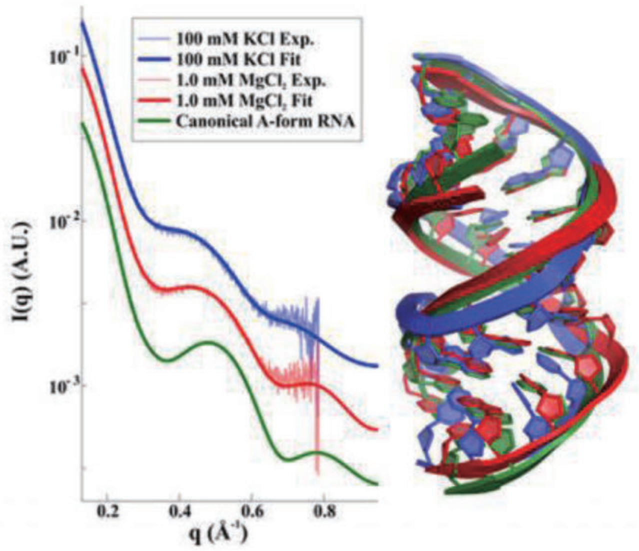


Figure (right): Experimental X-ray scattering curves for RNA duplexes in solutions containing different concentrations of KCl and $MgCl_2$. Right: RNA conformations resulting form the experimental data in comparison with the canonical RNA structure.

Setting Carriers Free: Healing Faulty Interfaces Promotes Delocalization and Transport in Nanocrystal Solids

Superlattices of epitaxially connected nanocrystals (NCs) are model systems to study electronic and optical properties of NC arrays. Annealing PbSe superlattices at 150^{o}C leads to a pronounced enhancement of the charge carrier mobility and a reduction of the hopping activation energy. Since the superstructure remains intact at these annealing temperatures, X-ray diffraction studies at CHESS focused on structural disorder at the atomic scale. From rocking curve XRD measurements and a Williamson-Hall size-strain analysis, researchers find that the atomic disorder of as-deposited NC arrays mainly originates from NC mosaicity, leading to edge dislocations and point defects. Through gentle annealing of the NC superlattices, both the density of edge dislocations and point defects are reduced, pointing toward the connection between defect density and optoelectronic properties of the NC superlattices. *ACS Nano* ***13****, 12774 (2019)*

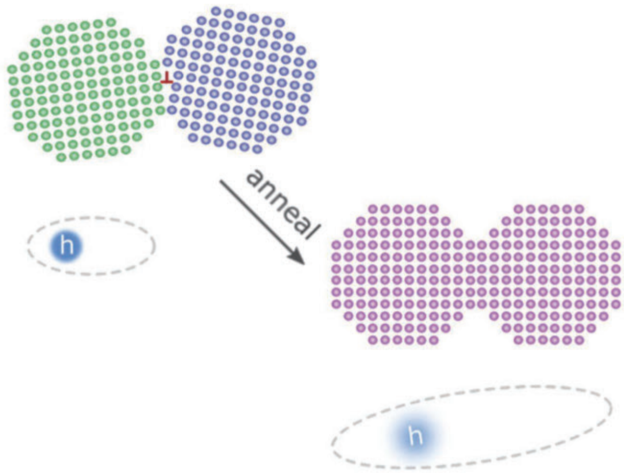


Figure (above): Mild annealing of NC superlattices decreases the density of point defects and edge dislocations which enables carrier delocalization over multiple NCs.

Unmasking continental natal homing in goliath catfish from the upper Amazon

The Amazonian goliath catfish *B. rousseauxii* has a complex life cycle, involving partial migration even in the absence of physical barriers, in the upper Amazon Basin. Researchers at CHESS made a methodological advance by establishing that synchrotron X-ray fluorescence microscopy (SXFM) can image elemental distributions of strontium, calcium, and selenium which provide information about fish life cycles consistent with and complementary to strontium isotope analysis. *Freshwater Biology, 65, 2 (2019).*

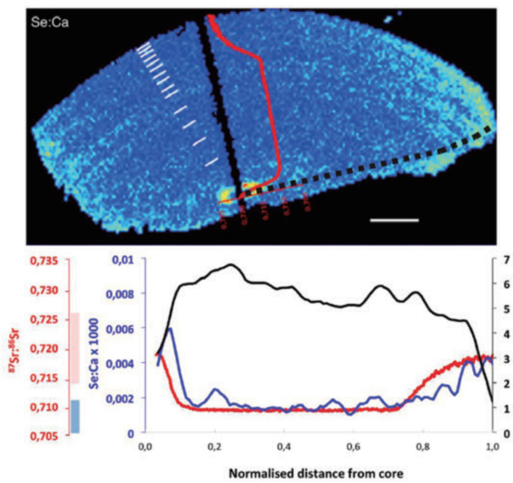


Figure (right): Chemical profiles of a specimen performing regional natal homing in the upper Madeira River. The solid black line indicates location of the $^{87}Sr:^{86}Sr$ profile (red). Scale bar = 1 mm.

The National Synchrotron Light Source II (NSLS-II)

General Information

The National Synchrotron Light Source II (NSLS-II) at Brookhaven National Laboratory in New York (USA) is one of the newest, most advanced 3rd generation synchrotron facilities in the world.

As a U.S. Department of Energy (DOE) Office of Science User Facility, NSLS-II opened its doors to users in 2015 and enables its growing user community to study materials with nanoscale resolution and exquisite sensitivity by providing cutting-edge capabilities.

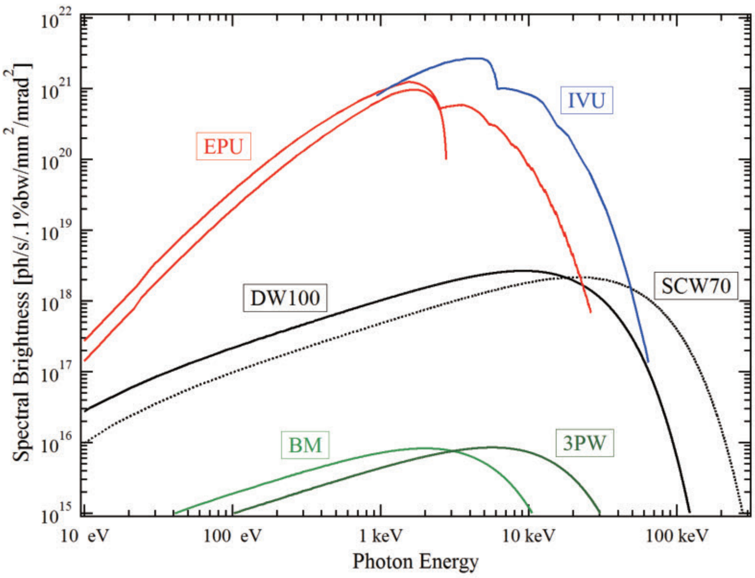
NSLS-II currently has 28 beamlines in operation and another one under construction. When built to full capacity, NSLS-II will have approximately 60 beamlines.

NSLS-II at a Glance

- User operations started in 2015
- 3.0 GeV electron storage ring
- 400 mA top-up operations, with final goal of 500 mA
- 28 beamlines in operation, 1 more beamline under construction, and a cryo-electron microscopy facility opening in 2020
- 5000 hours of user operation in FY 2019
- Almost 3000 unique users since 2015 and 1755 unique users in FY 2019
- 3 proposal cycles per year (deadlines Jan 31, May 31, Sept 30)
- ~700 proposals and time requests submitted each cycle, ~40% approved in FY 2019.
- >325 publications in refereed journals in 2019
- **https://www.bnl.gov/ps/**

About the Accelerator

NSLS-II is a medium energy (3.0 GeV) electron storage ring designed to deliver photons with high average spectral brightness exceeding 10^{21} ph/s in the 2 – 10 keV energy range and a flux exceeding 10^{15} ph/s in all spectral ranges. This performance requires the storage ring to support a very high-current electron beam (I = 500 mA) with a very small horizontal (down to 0.5 nm-rad) and vertical (8 pm-rad) emittance. The electron beam is stable in its position (<10% of its size), angle (<10% of its divergence), dimensions (<10%), and intensity (±0.5% variation).



Brightness versus photon energy for a number of different NSLS-II radiation sources at 3 GeV and 500 mA.

The National Synchrotron Light Source II (NSLS-II)

General Information

Hard X-Ray Spectroscopy
6-BM (BMM): Beamline for Mater. Measurement
7-ID-1 (SST-1): Spectroscopy Soft and Tender
7-ID-2 (SST-2): Spectroscopy Soft and Tender
7-BM (QAS): Quick X-ray Absorption and Scattering
8-ID (ISS): Inner Shell Spectroscopy
8-BM (TES): Tender X-ray Absorption Spectroscopy

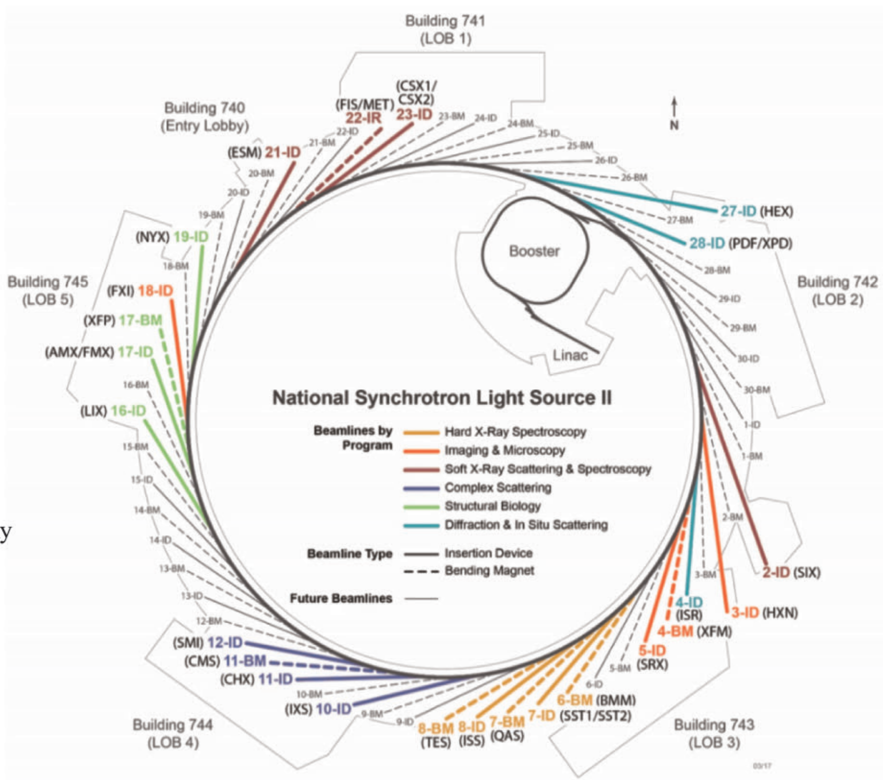
Imaging & Microscopy
3-ID (HXN): Hard X-ray Nanoprobe
4-BM (XFM): X-ray Fluorescence Microscopy
5-ID (SRX): Sub-micron Resolution X-ray Spectroscopy
18-ID (FXI): Full-Field X-ray Imaging

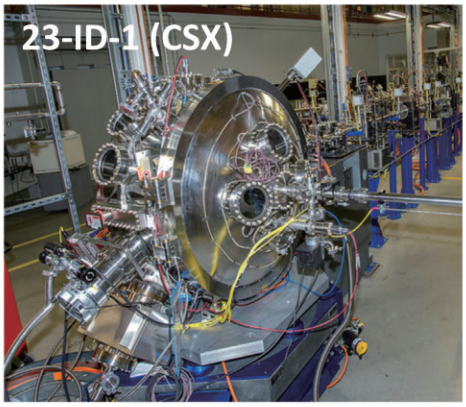
Structural Biology
16-ID (LiX): X-ray Scattering for Biology
17-ID-1 (AMX): Flexible Access Macromolecular Crystallography
17-ID-2 (FMX): Frontier Macromolecular Crystallography
17-BM (XFP): Biological X-ray Footprinting
19-ID (NYX): Biological Microdiffraction Beamline

Soft X-Ray Scattering & Spectroscopy
2-ID (SIX): Soft Inelastic X-ray Scattering
21-ID (ESM): Photoemission Microscopy
22-IR (FIS/MET): Magneto, Ellips, High-P Infrared Spectroscopy
23-ID-1 (CSX): Coherent Soft X-ray Scattering
23-ID-2 (IOS): Soft X-ray Spectroscopy & Polarization

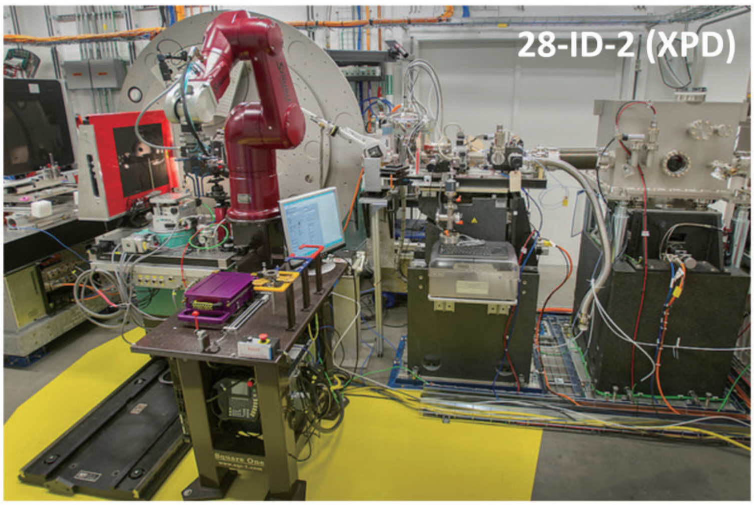
Complex Scattering
10-ID (IXS): Inelastic X-ray Scattering
11-ID (CHX): Coherent Hard X-ray Scattering
11-BM (CMS): Complex Materials Scattering
12-ID (SMI): Soft Matter Interfaces

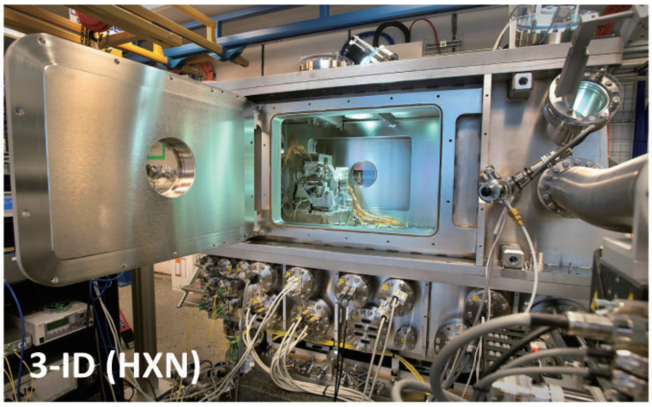
Diffraction & In Situ Scattering
4-ID (ISR): In-Situ & Resonant X-Ray Studies
27-ID (HEX): High Energy X-ray Diffraction
28-ID-1 (PDF): X-ray Pair Distribution Function
28-ID-2 (XPD): X-ray Powder Diffraction





The NSLS-II ring circumference is 792 m. Beamlines up to 72 m long can be built within the ring building in sectors with the extended experimental floor width, as compared to 66 m long beamlines in sectors with the standard floor width. Extra-long (>200 m) beamlines extending beyond the exterior walkway with endstations located outside the ring building are also possible.

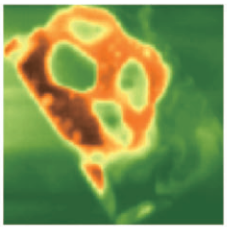




The National Synchrotron Light Source II (NSLS-II)

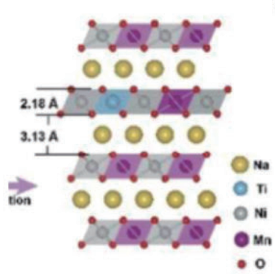
Current Activities

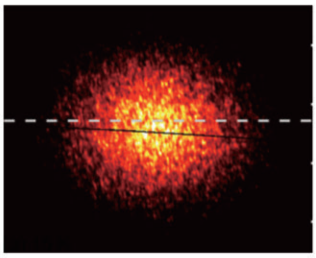
Each beamline at NSLS-II offers unique, cutting-edge research tools, including high-throughput robot-driven sample processing, coherent scattering, unprecedented spatial and energy resolution, and a hard x-ray microscope with world-leading, nanometer spatial resolution. The beamlines at NSLS-II are organized into six scientific programs, based on the research techniques they offer, as described below.



The **Imaging & Microscopy** program takes full advantage of NSLS-II's high brightness and small source size to image heterogeneous structures and chemistries under in-situ conditions. For example, high resolution elemental tracking at beamline 5-ID revealed the slow incorporation of Cu into a MnO_2 cathode, increasing conductivity and allowing it to achieve high cycle life. [*DOI: 10.1038/ncomms14424*]

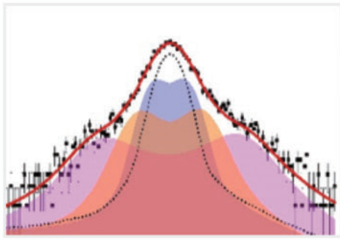
The **Hard X-Ray Spectroscopy** program strives to study real systems in complex environments over extended times. Its cutting-edge spectroscopy tools cover multiple wavelengths with high spatial and energy resolution and a wide range of photon and electron detection methods. For example, using x-ray absorption spectroscopy at beamline 8-ID, newly designed cathode materials for sodium batteries were shown to be stable when exposed to air. [*DOI: 10.1021/jacs.7b05176*]

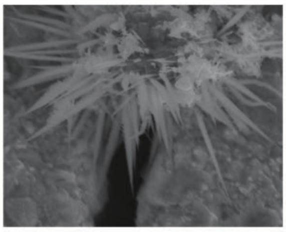




The **Soft X-Ray Scattering & Spectroscopy** program explores the scientific questions centered around the electronic properties and behavior in quantum materials. Through a unique suite of beamline end stations, the program enables the measurement of electronic structure with unprecedented spectral, spatial and temporal resolution. For example, using x-ray photon correlation spectroscopy at beamline 23-ID-1, the charge density waves in the cuprate superconductor $La_{2-x}Ba_xCuO_4$ were proven to be static in nature. [*DOI: 10.1103/PhysRevLett.117.167001*]

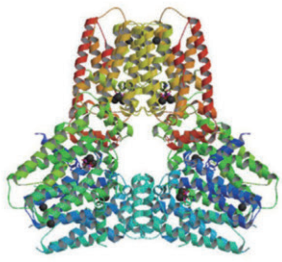
The **Complex Scattering** program uses the ultra-bright x-rays at NSLS-II and coherence to study complex mesoscale materials and the complicated dynamics of heterogeneous and non-equilibrium systems. For example, using inelastic x-ray scattering at beamline 10-ID, three distinct terahertz vibrations, which are common in solid matter, were detected moving through the layers of the Smectic A liquid crystal phase and were linked to the nanoscale structure of the material. [*DOI: 10.1021/acs.nanolett.7b01324*]





The **Diffraction & In Situ Scattering** program offers world-class tools to address a wide range of fundamental and applied material research problems under in-situ and operando conditions. For example, using hard x-ray diffraction at beamline 28-ID-2, remarkable corrosion resistance and impedance to ductility loss was exhibited by amorphous Fe-based coatings on steel under high radiation and corrosive environment. [*DOI: 10.1016/j.jnucmat.2016.04.001*]

The **Structural Biology** program offers an assortment of world-class tools that combine micro focus beams and high photon density to support a broad range of biomedical structure determination methods from serial crystallography on micron-sized crystals, to structure determination of complexes in large unit cells, to rapid sample screening and room temperature data collection of crystals in trays. It enables discovery-class research on fundamental biological questions. *[DOI: 10.1063/1.4952829]*



The National Synchrotron Light Source II (NSLS-II)

Partnership and Innovation in Synchrotron Radiation for the Future of Humanity

NSLS-II strives to enable a broad range of high-impact, discovery class science and technology programs to address the critical scientific challenges for the future of humanity. To achieve this goal, NSLS-II combines partnership and innovation in every operational and scientific aspect. NSLS-II considers four major aspects essential for its future, as described below.

New Beamlines and New Capabilities

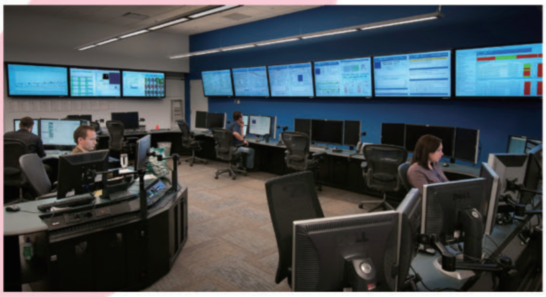
- Offering excellent conditions for cutting-edge science
- 28 operational beamlines and one new beamline under construction
- Providing 5000 hours of user beam time per year
- Offering multi-modal measurements and data acquisition at multiple beamlines
- Enhancing expertise and diversity of staff

Operational Excellence and New Technologies

- Reaching towards an operational current of 500 mA
- Beams allowing researchers to "see" details down to incredibly tiny scales, possibly even a single nanometer, small enough to resolve single molecules.
- Supporting facility R&D to advance synchrotron light source technologies, such as X-ray optics and detectors.

Collaboration and Partnerships

- Offering interactive and interdisciplinary collaboration opportunities
- Reaching out to diverse partners: government, universities, national laboratories and industry
- Connecting researchers with complementary expertise
- Integrating user interest to catalyze innovation
- Cryo-electron microscopy facility opening in 2020 to complement existing X-ray imaging tools



Data Acquisition and Analysis

- High-throughput beamlines
- Fast and easy data acquisition and online analysis
- Computing and storage resources available to users
- Refining data architecture for growing demands
- Advancing analysis tools to optimize productivity

Brazilian Synchrotron Light Laboratory (LNLS)

General Information

The Brazilian Synchrotron Light Laboratory (LNLS) operates the only synchrotron light source in Latin America. UVX is a second-generation 1.37 GeV storage ring that opened in 1997. It currently has 15 beamlines open for users, covering several experimental techniques using Infrared and UV radiation and X-rays.

Over the last few years, UVX has delivered around 3700 hours of synchrotron beam per year and its reliability has been about 97.5%, which is on par with competitive light sources.

Every year, LNLS facilities benefit around 1000 Brazilian and foreign researchers, resulting in approximately 200 papers published in peer-reviewed journals. The Laboratory also fosters partnerships with Brazilian industry in research, development, and innovation.

LNLS is currently building Sirius, a fourth-generation synchrotron light source, planned to be among the most advanced in the world. In fact, Sirius is designed to be the brightest among all facilities in its energy class. Sirius will open new research perspectives in many areas, such as materials science, nanotechnology, biotechnology, and environmental sciences.

LNLS is part of the Brazilian Center for Research in Energy and Materials (CNPEM), a non-profit private research and development institution under the supervision of the Brazilian Ministry of Science, Technology, Innovations, and Communications (MCTIC).

UVX:

Start of Operation	1997
Electron Energy	1.37 GeV
Current	250 mA, in decay mode.
Emittance	100 nm.rad
Beamlines	12 bending magnet beamlines, 3 insertion device beamlines

In 2016:

Beamtime for Users	3.838 hours
Reliability	97.8%
Number of Proposals	Submitted, 776 Approved, 460
Number of Users	954
User Origin	Brazil, 79%; Abroad, 21%
Publications	223

Figure 1: View of LNLS' UVX synchrotron light source.

Brazilian Synchrotron Light Laboratory (LNLS)

Current Activities

LNLS is currently building Sirius, the largest and most complex scientific facility ever built in Brazil.

Sirius will have a 3 GeV storage ring with a 5BA magnetic lattice and natural emittance of 0.25 nm.rad, making Sirius one of the brightest synchrotron light sources in the world in its energy class.

One innovation in the Sirius magnetic lattice is the introduction of high field 3.2 T permanent magnets in the middle of the central 0.58 T dipole of the 5BA cell. Besides contributing to the reduction of emittance, these high field dipoles will also produce hard X-rays with a critical photon energy of about 20 keV and usable photon flux up to about 120 keV.

Sirius will house up to 40 beamlines, six of which are considered long, with lengths ranging from 100 to 150 meters. In addition, the building is designed so that two extra-long beamlines can be built in the future, with experimental stations up to 250 meters away.

Construction started in January 2015 and is expected to last a total of 40 months. Plans call for Sirius to be inaugurated in June 2018 and opened for users by the end of 2019, when the first five beamlines will be delivered. Eight additional beamlines will be available by the end of 2020.

One of the goals for Sirius is to stimulate development of Brazilian industry. In 2016, more than 200 small, medium, and large Brazilian companies were involved with Sirius in some capacity and, among them, about 40 companies have been working on technology development especially for Sirius.

Sirius:

Start of Operation	2019
Electron Energy	3 GeV
Current	350 mA, in top-up mode.
Emittance	0.25 nm.rad

Figure 2: Sirius architectural concept.

Figure 3: Sirius accelerator tunnel design, with storage ring (left) and booster (right).

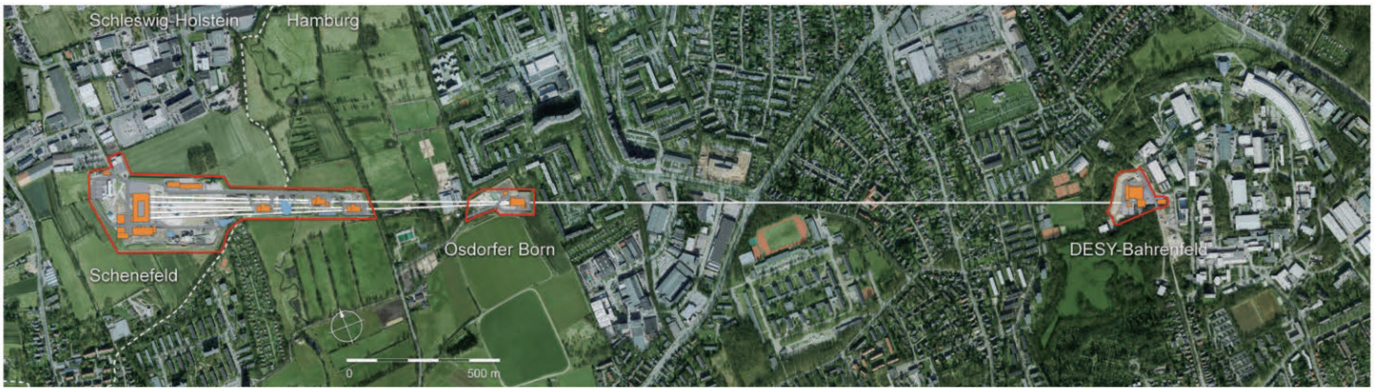
Figure 4: Aerial view of the Sirius construction site in August 2017.

European XFEL

General Information

The European XFEL is an international user facility generating soft and hard X-ray free-electron laser radiation for applications from multiple science areas, with a focus on physics, material and nanosciences, reaction chemistry, structural biology, and extreme states (as found in planets or dense plasmas). Funded in 2009, the first X-rays were obtained in May 2017 and the first user experiments started in September 2017. European XFEL is designed as a user facility serving several user groups in parallel. To enable concurrent use, the electron beam is distributed to 5 (initially 3) different undulators, each serving two or three end-stations.

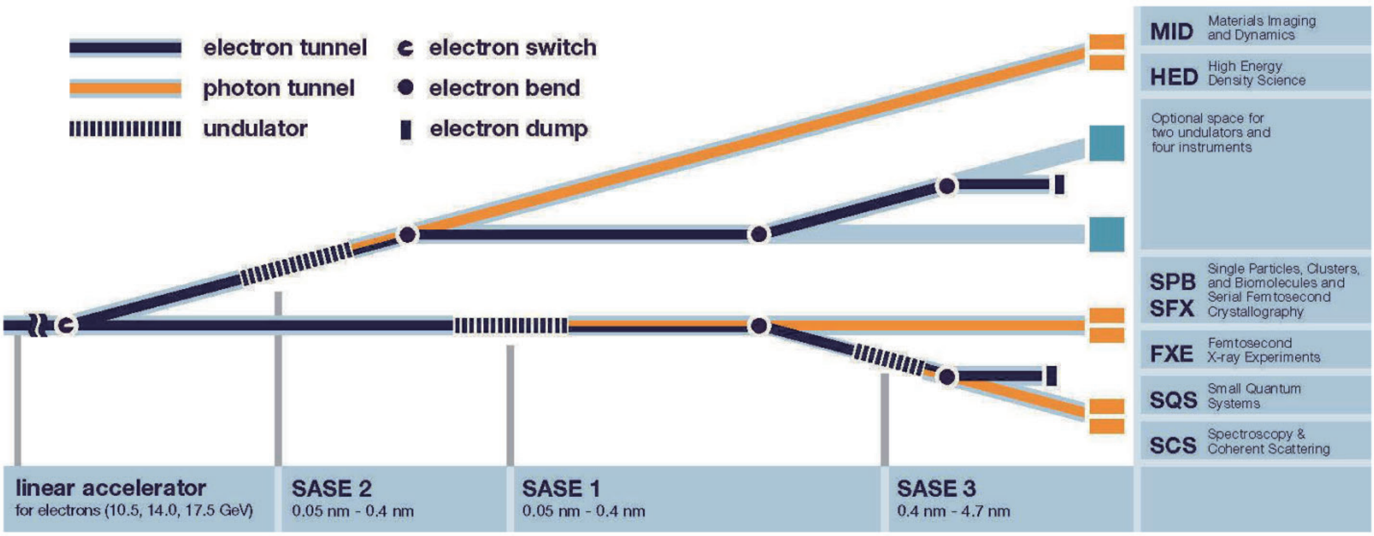
European XFEL is financed by contributions from its 12 shareholder countries: Denmark, France, Germany, Hungary, Italy, Poland, Russia, Slovakia, Spain, Sweden, Switzerland, and the United Kingdom.



User operations: started Sep 2017
Electron energy: 8.5 – 17.5 GeV
Number of FEL sources: 5 (3 at first)
Number of end-stations: 15 (max., 6 at first)
Photon energy: 0.25 – ~25 keV
Pulse duration: few fs - 100 fs
Annual operation for users: 4000 hrs
Construction budget: 1.22 B € (2005 value)
Operations Budget: 130 M €

Accelerator mounted in main XTL tunnel

Beamline Map



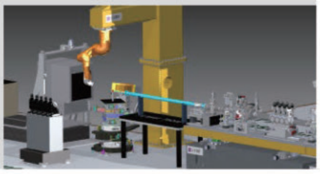
European XFEL

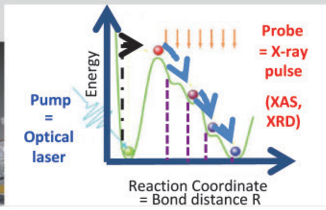
Science instruments and their application areas

FXE (Femtosecond X-ray Experiments)

The FXE instrument offers a world-wide unique and versatile end-station for time-resolved studies of ultrafast dynamics in various condensed matter systems, mainly liquids. For this purpose it exploits the high repetition rate, X-ray photon flux and ultrashort pulse duration of the European XFEL.

FXE offers a flexible sample environment optimized for liquid-phase photochemistry using a suite of complementary X-ray spectroscopic and scattering techniques in a pump-probe arrangement. Simultaneous measurements of several observables provide a more complete picture of the dynamics both of the solute and solvent molecules.



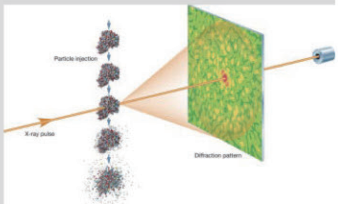


SPB (Single Particle, cluster, Biomolecules)

The SPB/SFX (Serial Femtosecond Crystallography) instrument aims to discern the structure–predominantly of biomolecules–that are prepared either as crystals or in non-crystalline form. The structure of biomolecules helps one understand how they work, and may be ultimately useful in combating diseases. The ultrabright X-ray pulses allow to "see" these tiny samples in almost atomic detail by illuminating them with an unprecedented flux of X-rays.

The SPB/SFX instrument operates in the forward scattering modality, from 3 –16 keV photon energy.

Two focal spots sizes, one of about 1 um and another ~100 nm, are available. Fast 2D detectors measure the crystalline and non-crystalline diffraction. Ancillary diagnostics and detectors further complement the instrumentation suite.

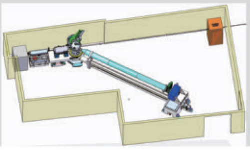


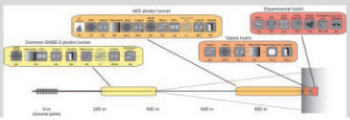
MID (Materials Imaging and Dynamics)

The MID station offers extended capabilities for scattering and imaging experiments, e.g. coherent X-ray diffractive imaging (CXDI) and X-ray photon correlation spectroscopy (XPCS), compared to present state-of-the-art facilities. Based on the high degree of coherence, the exceptional flux, and the ultra-short pulses of the X-ray laser it is possible to investigate materials with unprecedented resolution in space and time.

The MID beamline offers optics to collimate or focus the beam, and to tune the spectral bandwidth through single-crystal monochromators.

The MID sample chamber allows in-vacuum scattering and diffraction experiments on solid (crystalline and non-crystalline) and liquid samples. An X-ray split-delay line (up to 800 ps delay) enables ultrafast dynamics studies as well as for X-ray pump / X-ray probe experiments.

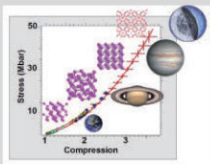


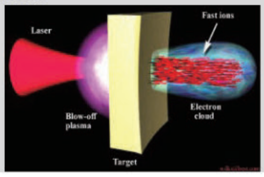


HED (High-Energy Density science)

The HED instrument enables the investigation of matter at extreme conditions of temperature, pressure electric and/or magnetic field strength. Major applications are high-pressure planetary physics, warm- and hot- dense matter, laser-induced relativistic plasmas and complex solids in pulsed magnetic fields.

The extreme states can be reached by different types of optical lasers (either 200 kHz/3 mJ/15 fs, 10 Hz/100 TW/30 fs or 10 Hz/100J/ns), the pump-probe FEL beam (delays of up to 2 -23 ps for 5 -20 keV using a split-and-delay unit) and pulsed magnetic fields (up to 50 T). Pump probe experiments can be performed at adapted repetition rates (4.5 MHz, 1 – 10 Hz, shot on demand). Available X-ray techniques comprise diffraction, imaging and spectroscopic methods





SCS (Spectroscopy & Coherent Scattering)

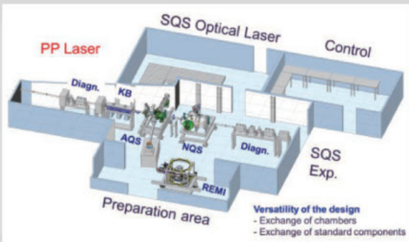
The SCS instrument is dedicated to the study of electronic, spin, and atomic structures on the nanoscale using soft X-rays. Areas of application are materials science, nanoscience, condensed-matter dynamics.

The SCS layout enables monochromatic-beam operation at high and medium resolving powers as well as pink beam operation. The Kirkpatrick-Baez mirrors provide an adjustable X-ray spot of up to 1 mm in size on the sample position with a 1.5 µm nominal focus. X-ray resonant diffraction, forward small-angle scattering, as well as absorption spectroscopy are baseline. The hRIXS apparatus adds the possibility for high resolution RIXS.

SQS (Small Quantum Systems)

The SQS instrument is dedicated to investigations of non-linear phenomena and time-resolved experiments on atoms, molecules, clusters and nanoparticles stimulated by intense and ultra-short FEL radiation pulses in the soft X-ray wavelength range. In addition to the Kirkpatrick-Baez focusing optics with a ~1 µm focal spot, main instrumentation are:

The AQS (Atomic-like Quantum Systems) chamber for investigations on small targets, the NQS (Nano-size Quantum Systems) chamber for investigations of clusters, nano-particles and bio-molecules, and the SQS-REMI (Reaction Microscope) chamber for studies on single-molecule dissociation dynamics.



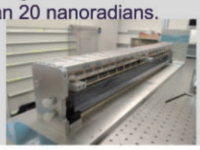
European XFEL

Instrumentation and major development activities

X-ray optics and beam transport

The beam transport system guides the X-ray laser beam from the undulators to the 1 km distant experiment hall in an underground tunnel system. Deflections of the X-ray beam are achieved by 950 mm long X-ray mirrors working in extreme grazing incidence angle geometry. To conserve the high degree of coherence and the shape of the laser beam, these mirrors have to be ultra-flat (larger than 6000 km residual bending radius) and ultra-smooth (less than 2 nanometers peak-to-valley polishing error over the entire mirror length).

Figure 1 shows a prototype mirror with piezo benders. Here, piezo actuators can be used to compensate for mounting errors and long-range polishing errors. To keep the mirrors mechanically stable in an ultra-high-vacuum environment, special mirror vacuum chambers were developed (Figure 2). Angular vibrations of a mirror mounted is such a chamber are better than 20 nanoradians.



X-ray photon diagnostics

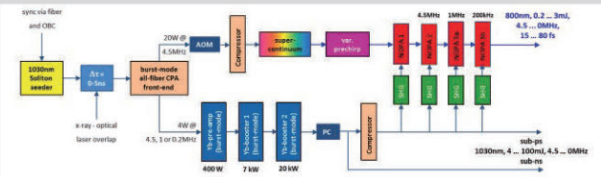
The photon diagnostics devices for monitoring the XFEL beam are placed into the photon transport system in the tunnels between the undulators and the experimental hall. The challenges for the functioning of these devices are the extremely high brilliance and the high repetition rate of 4.5 Mhz.

Currently each of the tunnels is equipped with X-ray residual gas monitors to measure pulse energy and position, partly pulse-resolved. In the hard x-ray beam lines SASE1 and SASE2 crystal-based spectrometers are installed to enable measurement of the spectral properties of the FEL beam. Using MHz 1D Gotthard detectors (developed by PSI) these measurements can be performed pulse-resolved. In SASE3 a photo-electron spectrometer (see Figure) has been installed for this purpose. Several imagers are installed along the beam lines to observe beam position (see Figure).

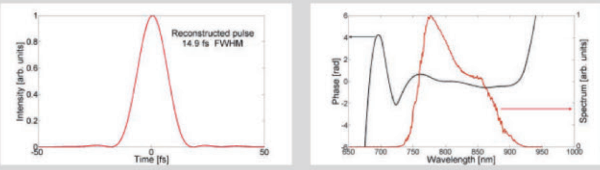
Optical lasers

A significant number of the experiments at the European XFEL (up to 75%) requires optical lasers for pump-probe experiments. Naturally, such a laser must be adapted to the European XFEL lasing-mode, i. e. it should deliver synchronized pulses of XFEL-comparable pulse width within bursts of 600µs length and an intra-burst repetition rate of up to 4.5MHz. Some degree of freedom in the choice of pulse width and wavelength (around 800nm) is also desirable. Energy requirements for single pulses usually range from µJ to mJ. Moreover, different experiments need different repetition-rates and pulse patterns inside the burst. Considering such difficult demands and lacking off-the-shelf commercial laser technology, the European XFEL developed their own pump-probe optical laser system.

The scheme of the European XFEL pump-probe laser is shown in the figure. It consists of a picosecond-pumped multi-stage non-collinear optical parametric amplifier (NOPA), employing an Yb-fiber based synchronized front-end, Yb:YAG pump amplifiers and dispersion managed super-continuum seed.



Scheme of the European XFEL pump-probe lasers installed in all beam lines.



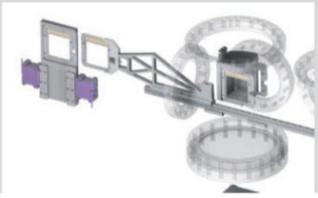
Complete characterization of 15 fs NOPA output pulse using SPIDER. Left: Intensity. Right: Spectrum and spectral phase. The pulses have a peak to pedestal contrast of 20dB.

The installation of all three lasers systems has been completed. The SASE1 system has been successfully applied to several user experiments already, SASE3 has commenced user operation. The SASE2 system is entering the commissioning with beam phase.

Sample environment

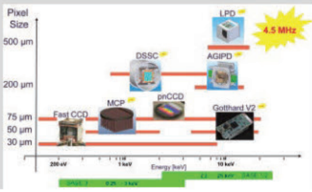
The high repetition rate of the European XFEL (2.700 bunches ten times a second) opens chances for experiments that are too time consuming for lower repetition rate sources. However, to make use of this feature, sample environments for fast and precise sample exchange have to be available. The Sample Environment Group developed and provides now state of the art sample delivery technologies for liquids, solid samples, magnetism and biology.

Liquid jet systems are the work horse of sample delivery for nano-crystallography, one of the most applied applications of XFELs. For solid samples or samples fixed to surfaces a 10Hz sample scanner has been developed.



Detectors

High-speed imaging X-ray detectors are essential for users to exploit the full potential of the ultrafast burst mode of the European XFEL and record valuable data. In collaboration with national and international partners, the Detector Development group developed ultrafast large- and small-area X-ray detectors required by the science experiments for imaging, monitoring, and spectroscopic applications. Low electronic noise, large dynamic range up to 10^5, the possibility to discriminate single photons from electronic noise with high significance up to 5σ, high angular resolution and the ability to endure the high demands on irradiation damage are essential detector performance parameters required to exploit the full potential of the European XFEL



How European XFEL contributes to solving societal challenges

The European XFEL and health problems of the 21st century

Over the last half century, scientists have gained much deeper insights into the mechanisms of life, but numerous questions remain. The X-ray flashes of the European XFEL now enable scientists to analyze the structures of many more biomolecules and biological entities, such as proteins, cells, and membranes.

Moreover, researchers will be able to study how these entities change while working. Understanding the structure of the entities, as well as their temporal changes, will provide insights into their functions, and is expected to form an important basis for the development of future medicines, such as antiviral drugs.

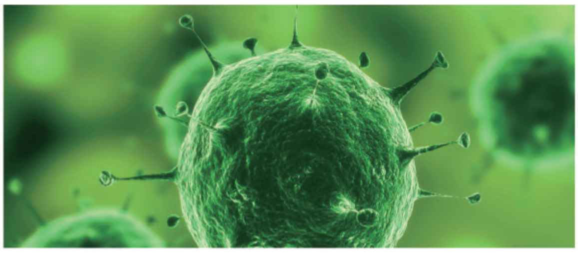
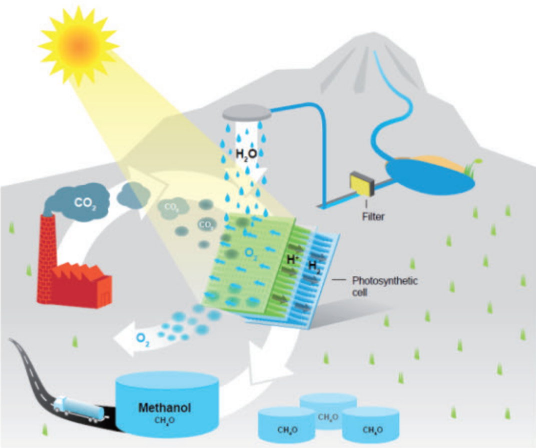


Figure 6: Viruses such as HIV or influenza, with diameters between 80 and 150 nanometres (billionths of a metre) in size, rely on specialized biomechanical and biochemical processes to infect cells. The European XFEL is expected to show in unprecedented detail how these infections occur, possibly unlocking more effective and more targeted treatments for the diseases these viruses cause. Credit: fotolia



The energy challenge: Natural and artificial photosynthesis

A better understanding of processes in our environment at the atomic level will provide deeper insights into the drivers for environmental change. It will also help us to find new solutions, e.g. to address problems such as artificial photosynthesis,. The intense X-ray flashes of the European XFEL will support the development of new catalysts and the replacement of rare or toxic materials in industrial production. For example, scientists can examine soot particles with the aim of developing more efficient combustion processes or nanomaterials that minimize their eventual environmental impacts.

Growing populations and developing economies require increasing amounts of energy, but resources are limited. Many known sources of energy are either running out or their use degrades the environment. To address these challenges, scientists can use the X-ray flashes of the European XFEL to study processes occurring in solar cells and fuel cells. The flashes will also help them to create and analyze plasmas that could potentially be exploited for the development of future fusion reactors.

Materials and processes for advanced technologies

Over the past few decades, a vast number of new materials have been developed. X-ray science has played an important role in many of these developments. However, properties such as durability, conductivity, or magnetization can still be better tailored to meet specific needs. Experiments at the European XFEL, which measure structural and dynamic properties of materials simultaneously, help to improve known materials and to develop new ones with revolutionary characteristics.

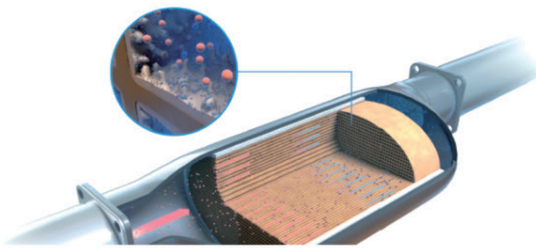
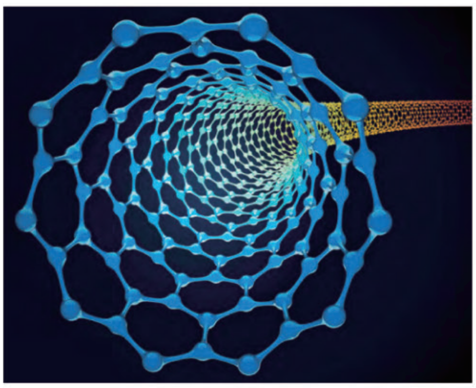


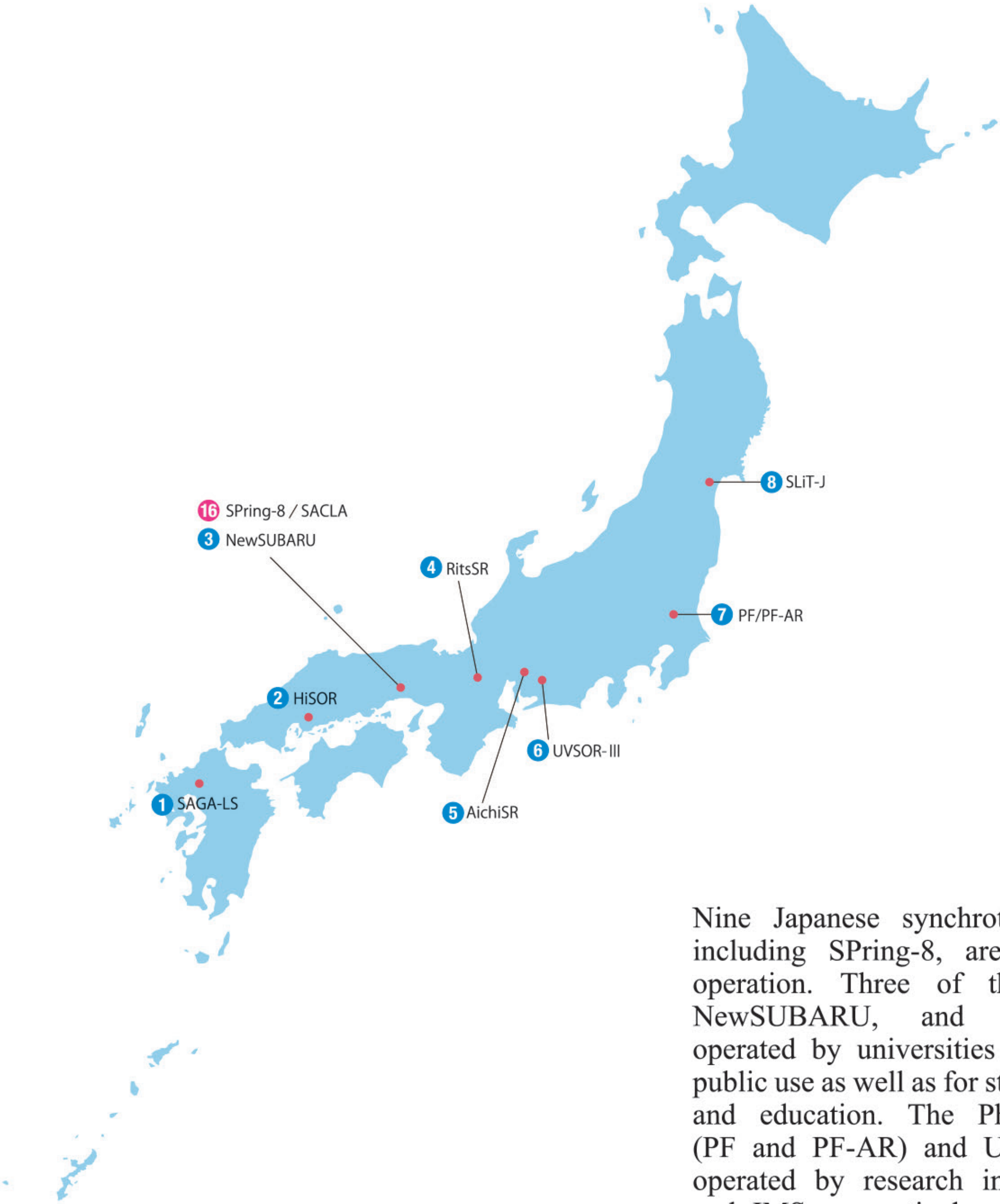
Figure 11: A car's catalytic converter, which helps reduce pollution in the exhaust. The European XFEL could improve the understanding of the process of catalysis and help make more efficient, less toxic catalysts. Credit: DESY

Our daily lives would be unthinkable without the inexorable progress made in electronics and computer technology. Faster chips and hard discs providing more memory require an ever better understanding of the properties of materials and how to optimize them. Research at the European XFEL offers new insights into the nanoworld, into magnetism, and into the properties of materials, with potential applications for even faster computers and greater data storage capacity.



We are able to artificially produce structures at smaller and smaller levels. Already, nanomaterials are part of our daily lives. Such materials are composed of structures that are between approximately 1 and 100 nanometers in size (that is, between one billionth and a ten-millionth of a meter). At this level, materials exhibit surprising new properties, often depending on the size of the particle. The short wavelength, high coherence, and ultrashort X-ray flashes of the European XFEL are ideally suited to investigate the spatial structures and temporal behaviors of nanomaterials. These insights could lead to new tailor-made nanomaterials, thereby laying the foundation for tomorrow's technologies.

Synchrotron Facilities in Japan



Nine Japanese synchrotron facilities, including SPring-8, are currently in operation. Three of them, HiSOR, NewSUBARU, and RitsSR, are operated by universities and open for public use as well as for student research and education. The Photon Factory (PF and PF-AR) and UVSOR-III are operated by research institutes, KEK and IMS, respectively. Aichi SR and SAGA-LS, which are operated by local governments, provide research tools mainly for industrial users on materials including local products. A new 3 GeV synchrotron facility, SLiT-J, is currently under construction in the Tohoku area. It will serve academic research and industrial applications.

1

Tosu, Saga P.106~

SAGA Light Source(SAGA-LS)

The only synchrotron facility in Kyushu area. It is established by Saga prefecture, and have the aim of, for example, development of local industry, human resource development or public relations for science and technology.

【Operation start】 2006
【Circumference】 75.6m
【Energy】 1.4GeV
【Beamlines】 11

2

Higashi Hiroshima, Hiroshima P.108~

Hiroshima Synchrotron Radiation Center (HiSOR)

HiSOR is the only synchrotron facility established inside the national university in Japan, and authorized as the Joint Usage/Research Center by the MEXT. HiSOR promotes the advanced condensed matter physics using synchrotron radiation in the VUV and SX range, and develops the next-generation human resources as a facility attached to the university.

【Operation start】 1997
【Circumference】 22m
【Energy】 0.7GeV
【Beamlines】 15

3

Ako-gun, Hyogo P.110~

NewSUBARU

Operated by University of Hyogo inside the SPring-8 campus. Typical examples are material analysis and ultra-fine processing by EUV and soft X-rays. Gamma-ray experiment is also performed.

【Operation start】 2000
【Circumference】 118m
【Energy】 1.0～1.5GeV
【Beamlines】 9

4

Kusatsu, Shiga P.112~

Ritsumeikan University Synchrotron Radiation Center (RitsSR)

First synchrotron facility attached to university in Japan. Downsized by using superconducting magnets. Industrial application is open for use as well as research and education by academic users.

【Operation start】 1996
【Circumference】 3.14m
【Energy】 0.575GeV
【Beamlines】 13

5

Seto, Aichi P.114~

Aichi Synchrotron Radiation Center (Aichi SR)

Regional joint-use facility in "Knowledge Hub Aichi" project, promoted by collaboration among industry, academia and government. More than 50% of users from industry support high quality of manufactured goods in Aichi.

【Operation start】 2013
【Circumference】 72m
【Energy】 1.2GeV
【Beamlines】 11

6

Okazaki, Aichi P.116~

Ultra Violet Synchrotron Orbital Radiation Facility (UVSOR-III)

Constructed as a second generation light source in Institute for Molecular Science, and upgraded into the third generation. Reveals molecular structures and dynamics in chemistry, biology, environment and energy.

【Operation start】 1984 /2012(III)
【Circumference】 53m
【Energy】 0.75GeV
【Beamlines】 14

7

Tsukuba, Ibaraki P.118~

Photon Factory Ring (PF) ／ Photon Factory Advanced Ring (PF-AR)

The Japanese first X-ray synchrotron radiation facility and upgraded several times over the past 30 years. Operated by the Institute of Materials Structure Science (IMSS), the High Energy Accelerator Research Organization (KEK). Accepts graduate students as Inter-University Research Institute Corporations. PF-AR is a synchrotron radiation facility with high-intensity single-bunch mode, suitable for time-resolved experiments.

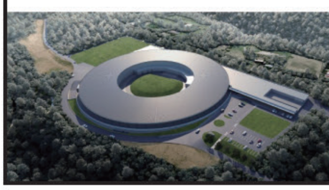
【Operation start】 1982／1987
【Circumference】 187m／377m
【Energy】 2.5GeV／6.5GeV
【Beamlines】 39／8

8

Sendai, Japan (planned) P.120~

Next Generation 3GeV Synchrotron Radiation Facility project

Project of constructing middle-sized synchrotron facility by a new organization "Public–Private Regional Partnership", in which the partners are the National Institute of Quantum and Radiological Science & Technology (QST), Tohoku University, Miyagi Prefecture, Sendai-City; the Tohoku Economic Federation; and the Photon Science Innovation Center.



Funding comes from private sector investments, local governments, and MEXT through QST. Aimed to meet various needs in industrial applications.

【Operation start】 2023 (planned)
【Circumference】 354m
【Energy】 3GeV
【Beamlines】 26

SAGA Light Source

General Information

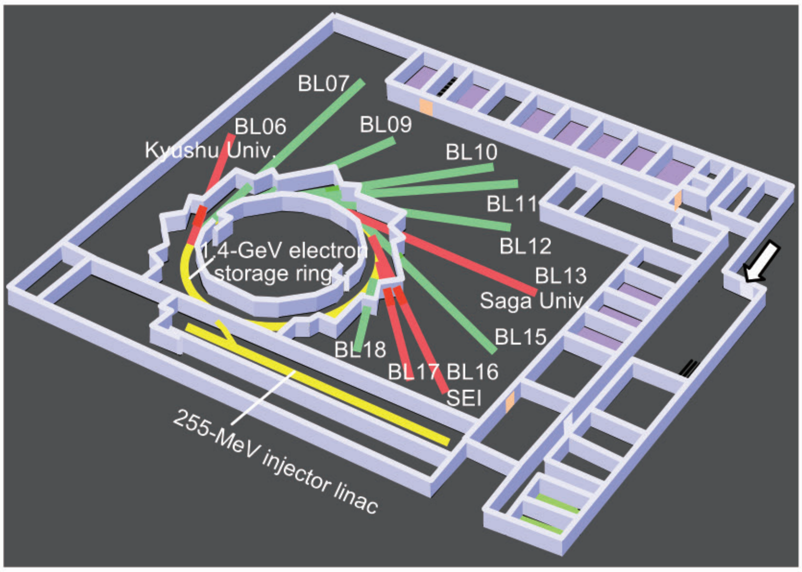
SAGA Light Source (SAGA-LS) is one of the eight synchrotron radiation facilities in Japan. It was the first local facility, which was established by Saga prefecture in Kyushu area. In 1999, the aims of facility was settled as follows;

1. Development of local industry and creation on new industry
2. Accumulation a lot of intelligence
3. Human resource development
4. Creation of industry-academia collaboration base
5. Public relations for science and technology

The facility was built at the northern part of Tosu-city in Saga prefecture, and has been open to user experiments since 2006. The recent situation is as the tables and figures shown at lower part. 7 prefectural beamlines are open to general users. Applications are accepted at any time, and are collected on 15 in every month and sent for review. Ordinary the users can perform their experiments at the month after the next. The another category is prepared, in which a fee over 200,000 JPY per day is necessary not accompanied by result publish obligations.

There are also 4 contract beamlines. At two of them, managed by Saga University and Kyushu University, general users are available through the collaboration et al.

Layout of the experiment hall



Specifications of facility

Injection Linac	
Length	30 m
Electron Beam Energy	255 MeV
Storage Ring	
Circumference	75.6 m
Beam energy	1.4 GeV
Stored current (immediately after injection)	300 mA
Emittance	25 nm・rad

Outer view

Specification of beamlines

Beamline	Source	Experiment	Photon energy	Affiliation
BL07	Superconducting wiggler (4T)	Imaging (CT), XRD, XAS Irradiation	5 keV – 35 keV White (peak 8 keV)	Saga Prefecture
BL09	Bending magnet	Topography Irradiation (Micro fabrication)	5 keV – 20 keV White (peak 5 keV)	Saga Prefecture
BL10	Undulator (APPLE-II type)	ARPES, XAS, PEEM	40 eV – 900 eV	Saga Prefecture
BL11	Bending magnet	XAS, SAXS, XFS	2.1 keV – 23 keV	Saga Prefecture
BL12	Bending magnet	XAS, XPS	40 eV – 1500 eV	Saga Prefecture
BL15	Bending magnet	XRD,Topography, XAS	3.5 keV – 23 keV	Saga Prefecture
BL18	Bending magnet	EUV irradiation	~ 92 eV	Saga Prefecture
BL06	Bending magnet	XAS, SAXS	2.1 keV – 23 keV	Kyushu University
BL13	Undulator (Planar)	ARPES, XAS	36 eV – 800 eV	Saga University
BL16	Superconducting wiggler (4T)	XAS, XRD, SAXS	2 keV – 35 keV	SEI*)
BL17	Bending magnet	XPS, XAS	50 eV – 2000 eV	SEI*)

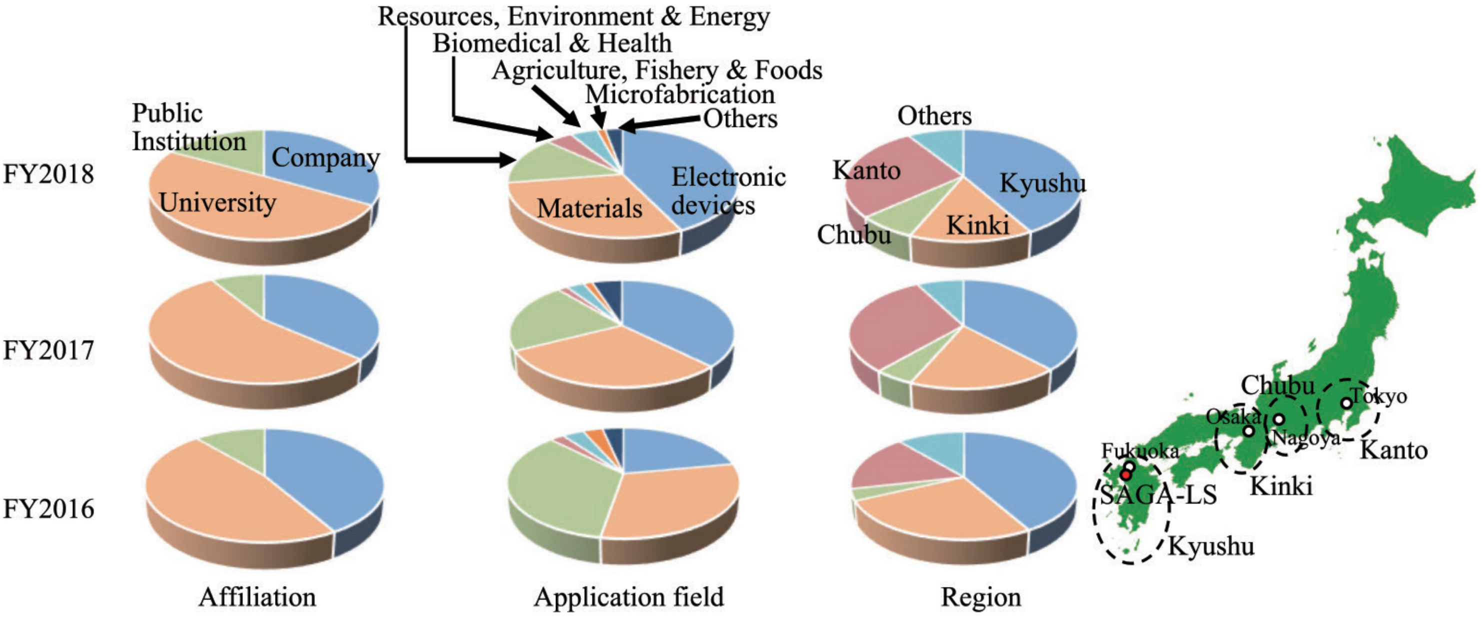
*) Sumitomo Electric Industries, Ltd.

Current Activities

A part of recent activities in SAGA Light Source (SAGA-LS) are shown at the figures in the lower part. Many application fields have been kept since 2006, when the facility was open to users. Near half of users are from Kyushu area, which shows that SAGA-LS is the local facility.
Available white light is one of the advantage of SAGA-LS. Because of not too strong, we can easily manage the white light. Recently, we are developing the measurement method utilizing white light such as quick imaging. In the example shown at lower part, CT image is acquired with the measurement time of only 100 sec. In case of the sample of plants or fish, which is the typical products in Saga prefecture, too long irradiation might affect during the measurement.
Other characteristic methods in SAGA-LS are for examples topography method or X-ray absorption method utilizing soft X-ray et al.

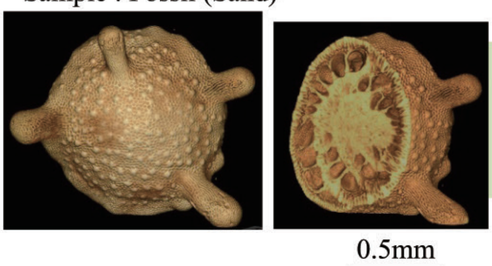
Statistics of user activities at SAGA-LS in fiscal 2016 - 2018

	2016	2017	2018
Total operation time	2206 hr	2270 hr	2163 hr
Total user time of prefectural beamline	1657 hr	1623 hr	1594 hr
Number of user projects	154	156	146

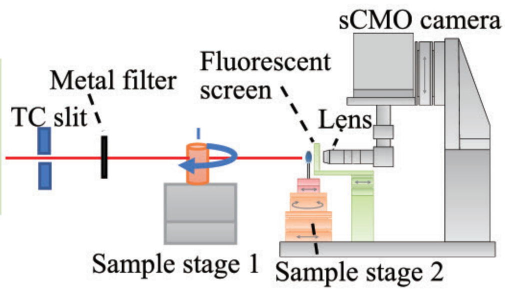


An example of recent development (imaging utilizing white or quasi white light) – BL07

Sample : Fossil (Sand)



Stage: Sample stage 2
Exposure time: 100msec /1 projection
Number of projection : 1000 / 360 deg
Total measurement time : 100 sec



Hiroshima Synchrotron Radiation Center, Hiroshima University

General Information

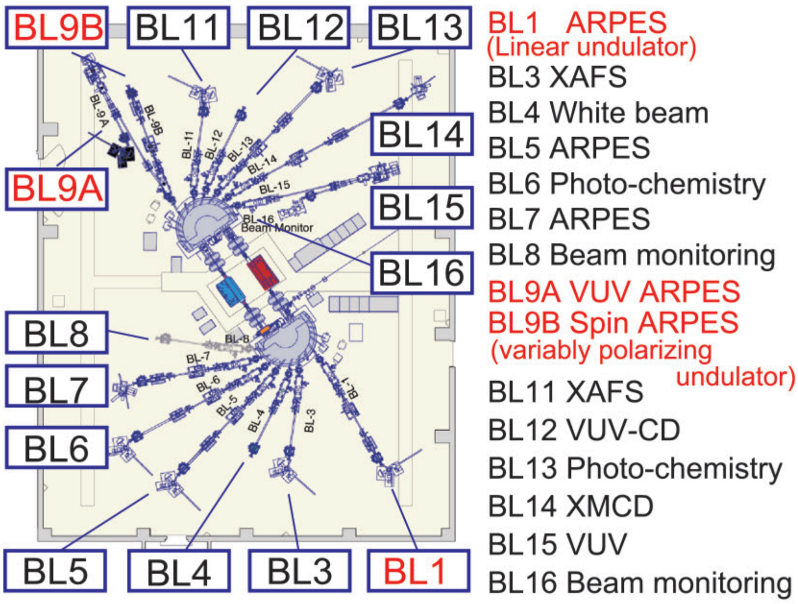
The Hiroshima synchrotron radiation center is the only synchrotron facility attached to a national university in Japan. It was established in 1996, as part of the academic policies of the Japanese government. A compact 700 MeV electron-storage ring, called HiSOR (the whole center is often referred to as HiSOR), produces synchrotron radiation in the vacuum ultraviolet (VUV) and soft X-ray (SX) range. This photon energy range is suitable for studying electronic states in solids (energy-band dispersions, Fermi surfaces, spin polarization, and many-body interactions). As described below, circular dichroism in the VUV region is also useful for structural studies of biomolecules in solution. The mission of the center is to promote advanced research in the field of condensed matter physics using synchrotron radiation in the VUV and SX range, as well as to develop human resources as a facility attached to the university.

In 2010, the center was authorized as a “Joint Usage / Research Center” by the Ministry of Education, Culture, Sports, Science and Technology (MEXT). As a result of extensive research activities in collaboration with researchers from Japan and other countries, MEXT awarded the center an “A” grade for the 1st term-end evaluation in 2015. In 2016, the center’s authorization as a Joint Usage / Research Center was extended for 6 more years.

During FY 2018, 228 researchers (actual number), including undergraduate and graduate students, completed 127 proposals. From 2004 to 2018, we have collaborated with researchers from 70 institutions in Japan and 71 institutions abroad. More than 20% of the researchers were from abroad, providing domestic students with an international atmosphere in the center.

Storage ring and beamlines

The accelerator system at the center consists of a 150 MeV injector microtron, a beam transport line, and a racetrack-type 700 MeV electron-storage ring (HiSOR). HiSOR has a circumference of 22 m, with a bending radius of 0.87 m in the normal conducting 2.7 T bending magnet, providing a critical photon energy of 873 eV. There are 16 beam ports: 2 for undulator beamlines and 14 for bending magnet beamlines. We have constructed 15 beamlines in total, including 2 beam monitoring beamlines. On the two straight sections of HiSOR, we have installed a linear undulator and a variably polarizing undulator (APPLE-II type). Each year, we provide about 1,500 hours for user beamtime.



Hiroshima Synchrotron Radiation Center, Hiroshima University

Current Activities

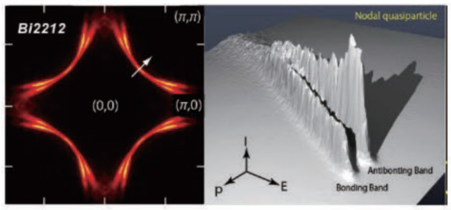
On the linear undulator beamline BL-1 (photon energy range: hν=22-300 eV), we have installed a unique rotatable angle-resolved photoemission spectroscopy (ARPES) system to investigate the symmetry of wave functions in solids, and fine electronic structures derived from the electron-phonon interaction near the Fermi level. On the variably polarizing undulator beamline, we have constructed two branch beamlines BL-9A (hν=5-35 eV) equipped with an ultrahigh resolution ARPES system and BL-9B (hν=16-300 eV) equipped with highly efficient spin- and angle-resolved photoemission spectroscopy (SARPES) system. BL-9A has enabled many studies on the fine details of the electronic states on the meV energy scales in high-Tc cuprates or strongly correlated materials with high momentum and energy resolutions with variable photon energy. BL-9B allows examinations of the three-dimensional spin structure of magnetic materials, as well as spin texture induced by the strong spin-orbit interaction in topological systems. BL-9B attracts many proposals, and more than half of the beamtime is allocated to collaborators from outside of Japan.

On beamline BL-12 (hν=2-10 eV), we have installed a vacuum ultraviolet circular dichroism (VUV-CD) spectrometer for the structural analysis of biomolecules (proteins, sugars, and nucleic acids) in solution. This experimental technique was developed at our center and has been recognized as a powerful tool to clarify the structures of a wide range of samples under various solvent/environmental conditions.

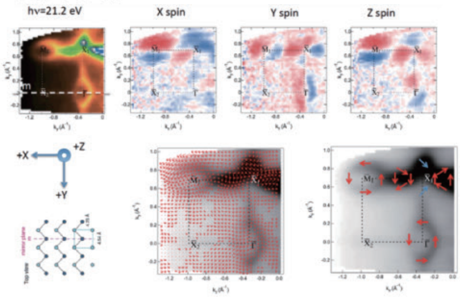
Beamline BL-14 (hν=400-1200 eV) enables users to prepare atomically-controlled thin films or nanostructures on substrates *in situ* and to characterize their magnetic and electronic properties by measuring the soft X-ray magnetic circular dichroism (SXMCD).

We are also developing a design for a compact low-emittance electron storage ring called HiSOR II for our future plans.

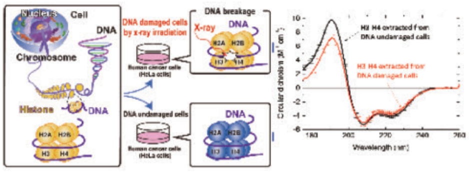
ARPES



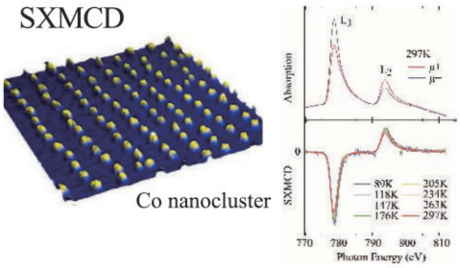
SARPES



VUV-CD



SXMCD



Human resource development and outreach

Being a part of the graduate school of science, Hiroshima University, the center is involved in fostering human resources not only through lectures and seminars, but also through research activities using synchrotron radiation. Undergraduate and graduate students can participate in domestic or international collaborative projects and directly learn about the latest research activities in the field.

Furthermore, the center hosts the Hiroshima International Symposium on Synchrotron Radiation (HiSOR Symposium) in March every year since its inauguration. In the 23rd HiSOR Symposium held in 2019, there were 10 oral presentations and 33 poster presentations, and 84 participants. Distinguished researchers in our priority research areas have been invited and given talks. Students presented their scientific achievements in the poster session. In a flash poster session of the symposium, all the students can give a short presentation to advertise their poster in English. To encourage students, we present the best poster awards to students in recognition of their excellence in scientific research and presentation.

We accept many visitors, including junior and senior high school students and international students. In 2018, 1,593 people visited our center.

NewSUBARU Synchrotron Light Facility

General Information

The NewSUBARU synchrotron light facility is operated by the Laboratory of Advanced Science and Technology for Industry (LASTI), University of Hyogo. This synchrotron facility, the largest synchrotron that belongs to a university in Japan, generates synchrotron light in the soft X-ray region. The facility consists of an electron storage ring and nine beamlines. Electrons are supplied from a 1 GeV linac as an injector from the SPring-8 facility. The following illustration shows the conceptual layout of the NewSUBARU synchrotron light facility. Nine beamlines are in operation, with R&D focused on extreme ultraviolet lithography, LIGA processes, chemical analyses, and novel light source studies.

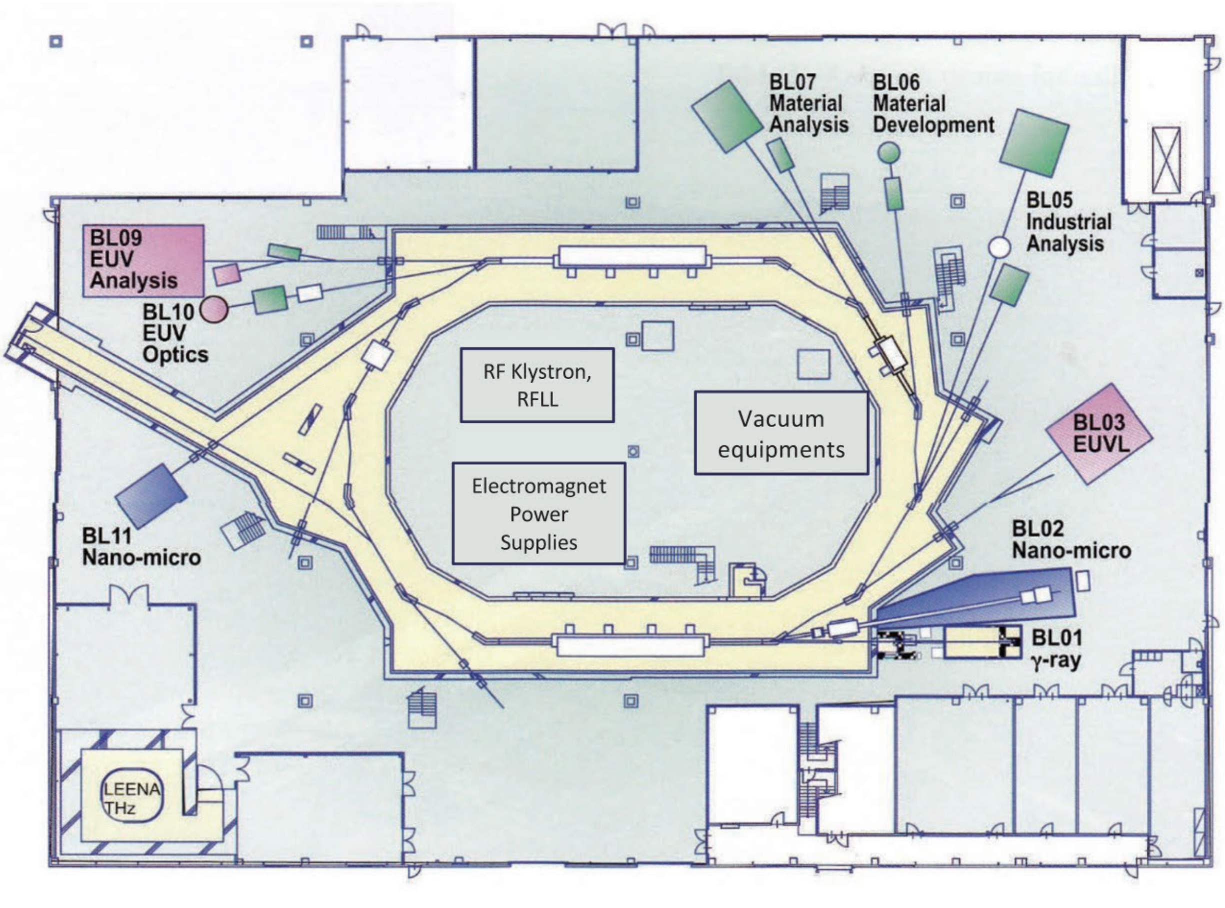
1) The BL01 gamma-ray beamline is used for nuclear physics research and the generation of high-energy positrons that are used for nondestructive material inspection.

2) BL02 and BL11 are the nano-micro manufacturing beamlines, using large area X-ray lithography in micron order and high aspect ratio pattering using LIGA processing technology.

3) BL03, BL09 and BL10 are beamlines for the R&D of EUV lithography for next generation semiconductor devices. The focus of development includes EUV resist evaluation technology and EUV mask inspection technology.

4) BL05, BL06, BL07 and BL09 are the material analysis beamlines using soft X-ray spectroscopy technology such as X-ray absorption fine structure, X-ray photoelectron spectroscopy, and X-ray emission spectroscopy.

All NewSUBARU beamlines are open for both industry usage and fundamental science research. Promotion of both use and technical assistance for industrial users is supported by MEXT's "Project for the Creation of Research Platforms and Sharing of Advanced Research Infrastructure".



NewSUBARU Synchrotron Light Facility

Current Activities

EUV Lithography for semiconductor devices

Development of microfabrication technology for semiconductors (Extreme ultraviolet lithography technology: EUVL) is finally ready for practical use! !
EUVL is applied to mass production technology of 7-nm node semiconductor chips for smartphones from 2019.

Outcome: Contributing to the practical use of EUVL
- EUVL exposure tool
- Resist material and processing technology
- Mask technology

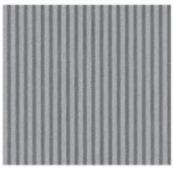
Effectiveness:
Energy-efficient ULSI Products
1) Low power consumption:
   DC3.3 V==>DC 0.1 V and below
2) Low cost:
   Cost reduction 1/500 /1kbit/year
3) Mobile: iPhone, iWatch etc.

Future plans:
Attaining and maintaining safety and the confidence of society
nanoIOT (ULSI, Quantum device with AI combination)
1) Reduced costs for medical insurance
2) Handy medical evaluation tool
3) Home automation
4) Fully automatic driving vehicle

Development of EUVL Exposure Tool
Development of picometer-class high-precision mirror technology

Mother board in smartphone Equipped with semiconductor chip

Semiconductor circuit



Smart phone

Development of ultra-fine resist
Resist pattern formation with long undulator (15 nm line width)

At University of Hyogo, EUVL basic technology development, which has been under development for 23 years at NewSUBARU, is a major contribution in breakthrough of the semiconductor field

Medical applications

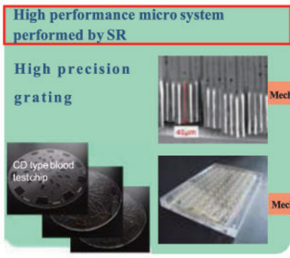
1) Compact high performance clinical diagnostics system
Using a micro chemical chip consists of 3D flow channel achieved by SR-LIGA process, we achieved successful integration of immunoassay functions for biomarkers such as adult disease.
As a Point of Care and Testing (POCT) system, pharmaceutical and medical equipment companies are watching closely.

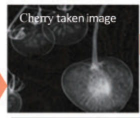
2) Development of optical elements for high performance X-ray diagnosis
To achieve x-ray phase imaging, a high precision x-ray element was developed, and using this element, it is succeeded in high-resolution imaging of biological samples at SPring-8.

Future plans:
1) Observation of biological soft tissues such as cartilage breasts, which have been difficult to observe conventionally methods.
   It may become possible to diagnose arthropathia or cancer significantly earlier.
2) It can be effectively used for industrial nondestructive inspections, such as internal defect inspection of electronic parts and resins.

◆Phase imaging / X-ray which brings out drastic diagnostic performance improvement

◆High performance POCT medical equipment





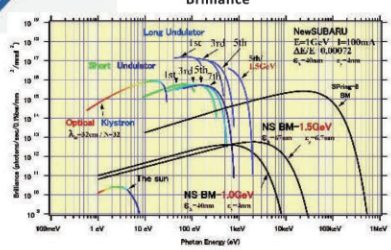
Effect
★Personalized medicine
★ Promotion of preventive medicine
★Reduction of medical expenses
★ Average working life extension

Overview of NewSUBARU

10.8-m Lomg Undulator

9 beamlines are operating
1) Fine patterning for semiconductors and micromachines
2) Chemical analysis for development of novel materials
3) Gamma ray applications

Brilliance

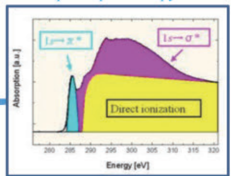


Analytical usage

Material analysis and material development using SR analysis
Analysis of various industrial materials such as photocatalysts, battery materials, hard films, 2D materials, etc.

Examples of using DLC in machinery, automobile, medical, and food

Structural analysis by X-ray absorption spectroscopy



Support
- As an example, we developed a structural analysis method of diamond-like carbon (DLC) used in many industries such as automotive Japan and Germany jointly proposed DLC ISO standard (ISO 20523)
- Industry exclusive analysis line that can be used by private companies (BL05)

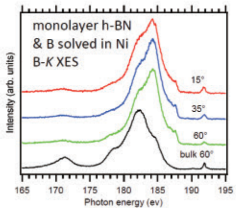
More than 30 companies / institutions use carbon material evaluation · valence determination of metallic elements etc.
- Collaboration work with Himeji City

Human resource development for practical engineers for private companies

ISO

Effect: XES and XAS of 2D materials and impurities
- Advanced analytical technology development using radiant light for the development of highly functional materials

-mapping technology using long undulator beamline BL09



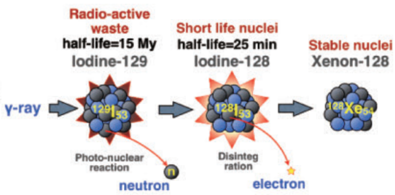
Analysis of 2D materials by X-ray emission spectroscopy

Industry exclusive analysis beamline

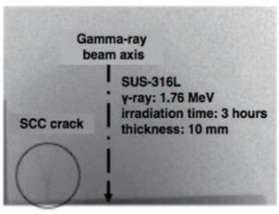
Applications using Laser Gamma-Ray

1. Selective transmutation by gamma rays, detoxification treatment of radioactive waste
2. Nondestructive inspection of steel materials using gamma rays
3. Material defect inspection using positrons
4. Acquisition of missing photonuclear reaction cross-section data using a laser Compton-scattering gamma ray source, BL01.

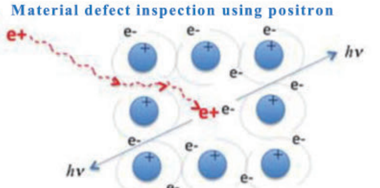
1. Selective transmutation
1) 93 Zr (half life = 1.53 million years)
   → 92 Zr (stable)
2) 79 Se (half life = 295 thousand years)
   → 79 Se (stable)
3) 107 Pd (half life = 6.5 million years)
   → 106 Pd (stable)



2. Nondestructive inspection of steel materials using gamma ray



3. Material defect inspection using positron



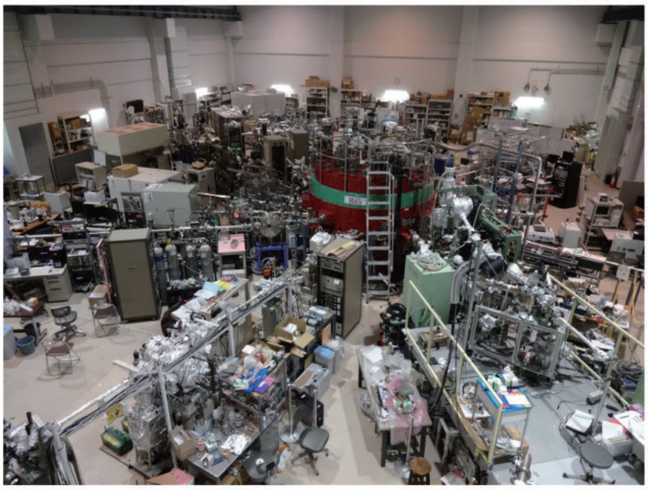
4. Acquisition of missing photonuclear reaction cross section data using laser Compton scattering gamma-ray source BL01.
1) International collaboration with universities
2) The IAEA-CRP research project
3) Reacquire contradictory cross-section data with a new measurement method (an international project, with 6 countries)

Ritsumeikan SR center

General Information

Overview

In 1996, Ritsumeikan University in Kyoto installed an accelerator complex for synchrotron radiation and inaugurated the SR center as a symbol of the Biwako-Kusatsu campus, which opened in 1994. This marked the first time that an SR facility had been installed in a university in Japan. The construction budget, 3 billion yen, was funded solely by alumni donations. The SR center has been actively used for synchrotron radiation research, the education and training of graduate and undergraduate students, and for industrial applications for more than 24 years without significant incident.



Accelerators

The storage ring named, "AURORA" is the smallest ring in the world with a one-body super-conducting magnet, developed by Sumitomo Heavy Industries. The accelerator specifications are as follows.

Ring Energy	575 MeV
Ring current (max)	300 mA
Circumference	3.14 m
Harmonic number	2
Critical wavelength	1.5 nm
Lifetime	5 hours
Natural emittance	1.6 mm rad
Operation time	10:00 - 20:30

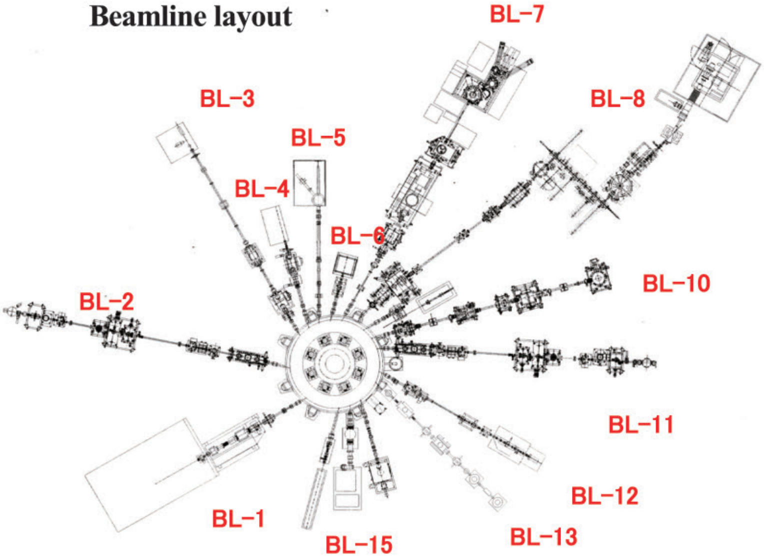
Statistics

- Operations budget (FY17) : US$1.2 million
- User beam time (FY17) : 1,300 hrs/year
- Number of registered users (FY17)
  - 283 from Ritsumeikan
  - 65 from other universities and national institutes
  - 48 from industry
- Number of proposals from external users (FY17)
  - 36 from universities
  - 59 from industry (proprietary use: 51)
- Number of presentations (FY17)
  - 35 papers in refereed journals
  - 34 in international conferences
  - 69 in domestic conferences

Beamlines

BL- 1	VUV spectroscopy (5-40 eV)
BL- 2	soft XAS (40 -1000 eV)
BL- 3	quick XAFS (4000-9000 eV)
BL- 4	imaging XAFS (4000-9000 eV)
BL- 5	dispersive XAFS (4000-9000 eV)
BL- 6	LIGA
BL- 7	2-D angle resolved PES (30 -300 eV)
BL- 8	PES (40-700 eV) +MEIS
BL-10	tender XAS (1000 -4000 eV)
BL-11	soft XAS (40-1000 eV)
BL-12	soft X-ray microscopy (40-800 eV)
BL-13	tender XAS (1000 – 5000 eV)
BL-15	infrared micro-spectroscopy

Beamline layout

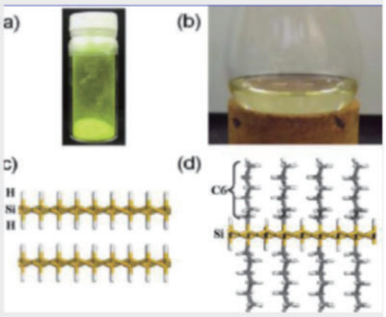


Ritsumeikan SR center

Current Activities

Tender XAS for characterizing Si nano-sheets

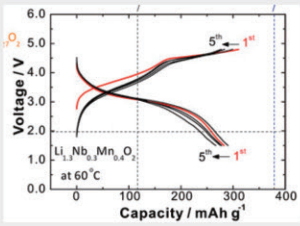
Hideyuki Nakano and his colleagues (Toyota Central R&D Lab.) successfully synthesized silicon nano-sheets by chemical layer-segregation of $CaSi_2$ and Si_2H_6. Substitution of H by several functional groups enables the sheets to have unique functions such as electrical conductivity and photo-conductivity.

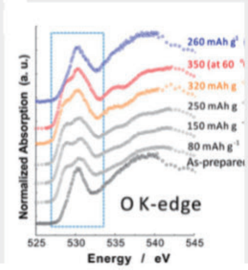


As these materials are all amorphous, Si K-XAS provides a powerful tool to characterize these materials.
Okamoto, *JACS* (2010)
Nakano, *JACS* (2012)

Soft XAS for new secondary batteries

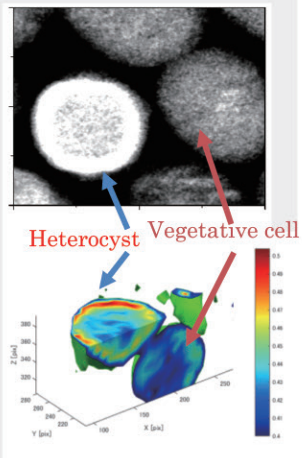
Naoaki Yabuuchi (Yokohama National Univ.) and his coworkers developed a high capacity secondary battery from $LiNb_xMn_{1-x}O_2$. In this battery, not only Nb and Mn, but also O play an important role for the charge/discharge processes. O K-XAS experiments have revealed the mechanisms of the battery.
Yabuuchi *et al. PNAS* (2016),
Nature Comm. (2017)





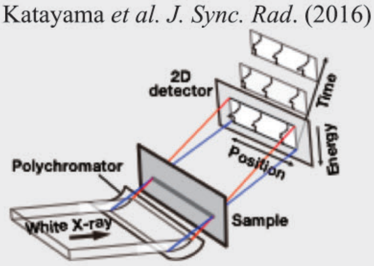
Soft X-ray microscopy for biomedical applications

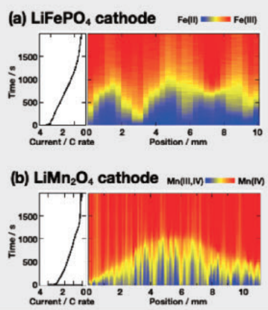
The center includes both infra-red and soft X-ray microscopic beamlines. The former is used for imaging specific functional groups in a sample, while the latter is used for imaging spatial distribution of a specific element. Takahiro Teramoto (Ritsumeikan Univ.) and his coworkers applied soft X-ray microscopy to study N-spatial distribution in a hetero-cyst and vegetative cell in cyano-bacteria. 2D and 3D images are shown in the two figures at right.
Teramono et al.
Plant Physiol. (2018)



Development of a vertically dispersive XAFS

A vertically dispersive XAFS method was newly designed and constructed, which enables us to obtain a series of dispersive XAFS spectra simultaneously in the horizontal direction. This method was successfully applied to trace the charging processes of the $LiFePO_4$ and $LiMn_2O_4$ electrodes.
Katayama *et al. J. Sync. Rad.* (2016)





Education and training of high school students

A course for synchrotron radiation is provided for high school students once per year. After attending a lecture about synchrotron radiation, about 20 students are divided into 5 -6 groups , which conduct separate experiments (such as XAFS, PES, SX-microscopy) under the supervision of beamline scientists. The following day, each group gives a presentation about their experiment. An international training course is also held on request.

Group photo of the staff and users at Ritsumeikan

Aichi SR

General Information

The Aichi Synchrotron Radiation Center (AichiSR) was built mainly for industrial use, following five years of discussion among universities, industries, and local government in the Aichi region of Japan. The top priorities for the initial six beamlines were XAFS beamlines capable of covering the elements from Li to U. In addition to hardware characteristics, user-friendly and efficient procedures for use were specified. The accelerators, six beamlines, and building were funded by the Aichi prefecture (50%), the Japanese government (30%), and donations from industry (20%). Public operations launched in March 2013. Currently, eleven beamlines are in operation serving a wide variety of fields of research.

Accelerators and Beamlines

Accelerators

Linac (50 MeV), Booster Synchrotron (50 MeV-1.2 GeV), and Storage ring (1.2 GeV) with 8 normal conducting bending magnets (normal bend: 1.4 T) and 4 superconducting bending magnets (superbend: 5 T). The critical energy of SR from the superbends is 4.8 keV.

Beamlines

The beamlines below cover an energy range from 30 eV to 29 keV.

BL1N2: Soft X-ray XAFS and XPS

BL2S1: Single Crystal X-ray Diffraction (Nagoya University)

BL2S3: DENSO（Contract beamline）

BL5S1: Hard X-ray XAFS

BL5S2: Powder X-ray Diffraction

BL6N1: Soft X-ray XAFS and XPS

BL7U: VUV Spectroscopy and UPS

BL8S1: Thin Film Surface X-ray Diffraction

BL8S2: X-ray Topography, X-ray CT, and X-ray Lithography (Aichi Prefecture)

BL8S3: Small and Wide Angle X-ray Scattering

BL11S2: Hard X-ray XAFS

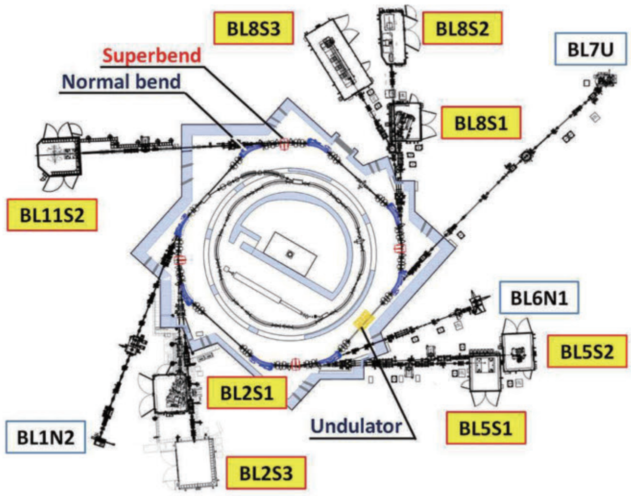
User operations started in March 2013.

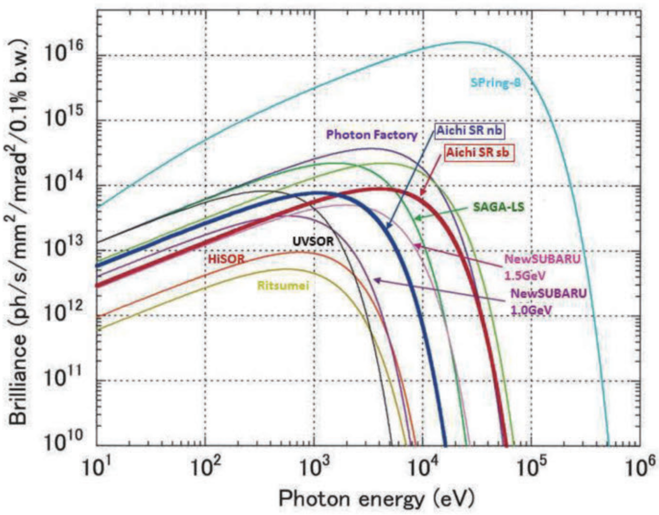
1.2 GeV 300 mA Top-Up operations.

2,022 hours of operation: 1,461 hours of user time, 555 hours stand-by and study time, and 6 hours downtime in 2018 FY.

Brilliance

Brilliance vs. photon energy from bending magnets for 8 SR facilities in Japan. The brilliance of AichiSR from its normal bend magnets is indicated by the blue line and from its superbend magnets by the red line. These brilliance curves were intentionally designed for the most typical use in Japan, and to be easy to use and sufficiently powerful. To meet these requirements, a storage energy of 1.2 GeV (for a compact ring with a circumference of 72 m) and magnetic fields of 1.4 T (normal bend) and 5 T (superbend) were chosen.



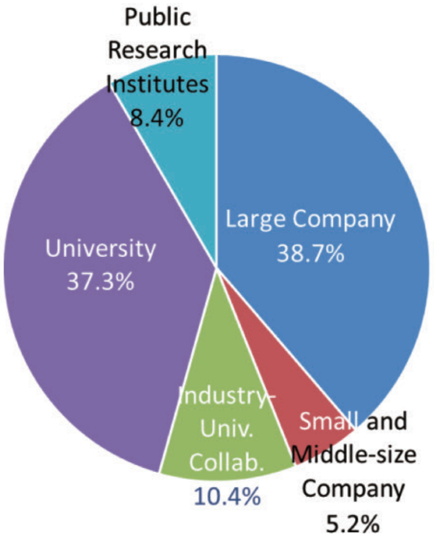


Aichi SR

Current Activities

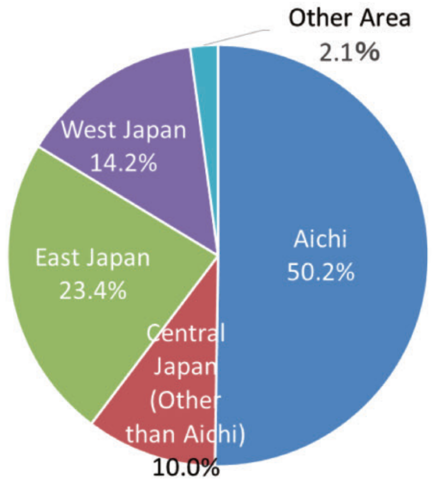
User Affiliation

AichiSR was intended primarily as a facility for industrial use, but is also available for academic use. The distribution of user time by user category is shown below, with the majority allocated to industry, as expected. However, usage by universities and public research institutes is growing rapidly. Though beam time is not free for academic use (costs are half of that for industrial use), these users see value in the quick response to user demands, support by coordinators, and helpful beamline staff.



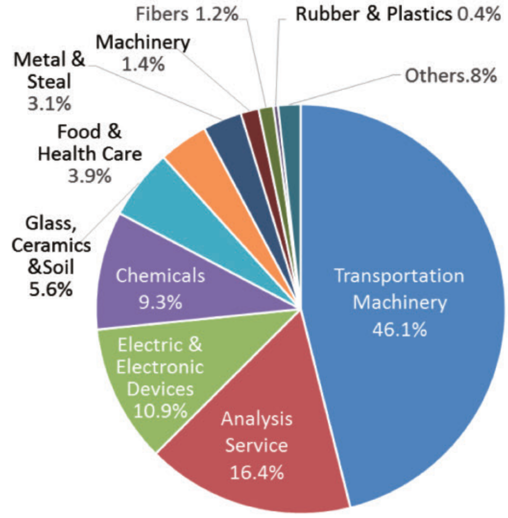
User Location

Usage from Aichi Prefecture is the highest as expected, but users come from across the country.



Research Field

Industrial users conduct research over a wide variety of fields, as indicated in the chart below. Since the Aichi region is the center for Japan's automotive industry, the largest category of research is in the transportation field.



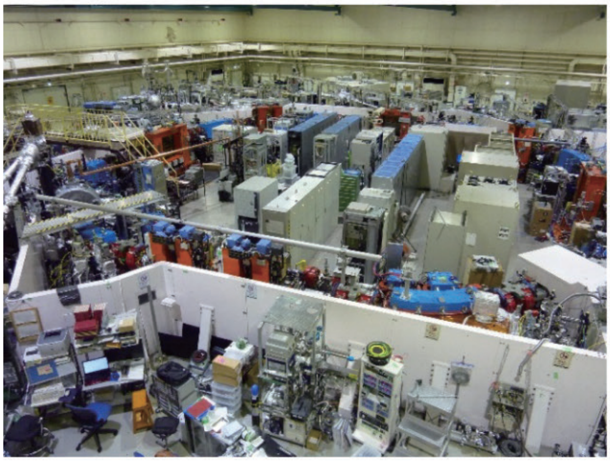
Knowledge Hub Aichi

A bird's-eye view of the Aichi Synchrotron Radiation Center and nearby facilities. The Aichi Center for Industry and Science Technology, located adjacent to AichiSR, houses laboratories, 18 state-of-the-art measurement and analysis devices, and offices. This area is known as "Knowledge Hub Aichi" and new research centers plan to locate nearby.

UVSOR-III Synchrotron

General Information

The UVSOR Synchrotron Facility in Okazaki, Japan, features a low-emittance electron storage ring, UVSOR-III, that is approximately 50 meters in circumference. The facility has 6 undulator beamlines (3 polarization-variable VUV and 3 in-vacuum soft X-ray undulators) and 8 dipole beamlines. The UVSOR-III Synchrotron, one of the brightest low-energy synchrotron light sources in the world, belongs to the Institute for Molecular Science (IMS). The facility has been leading cutting-edge research for chemical and physical science since 1983, when UVSOR-I launched.



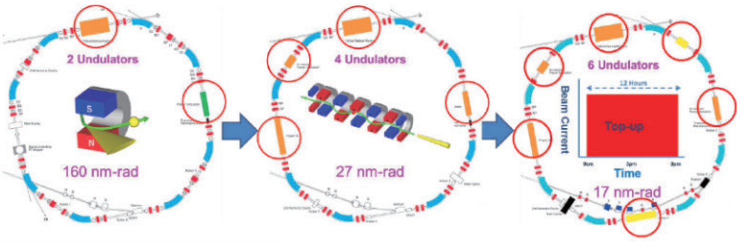
UVSOR-III Accelerator Complex

Booster Synchrotron	
Operation Energy	750 MeV
Injection Energy	15 MeV
Average Beam Current	~15 mA
Circumference	26.6 m
Bending Radius	1.8 m
Lattice	FODO x 6
Straight Section for I.D.	4 m × 4, 1.5 m × 2
Momentum Compaction	0.138
Betatron Tunes	(2.25, 1.25)

Linac	
Injection Energy	15 MeV
Peak Beam Current	~100 mA
Length	2.5 m
Frequency	2856 MHz
Gun HV	70 kV

Storage Ring	
Operation Energy	750 MeV
Injection Energy	750 MeV
Beam Current	300 mA
Natural Emittance	17 nm-rad
Circumference	53.2 m
Bending Radius	2.2 m
Lattice	Extended DBA x 4
Straight Section for I.D.	4 m × 4, 1.5 m × 2
Betatron Tunes	(3.60, 3.20)
Momentum Compaction	0.030
Energy Spread	5.4×10^{-4}
RF Frequency	90.1 MHz
RF Voltage	120 kV
Natural Bunch Length	128 ps
3rd Harmonic Cavity	One Installed

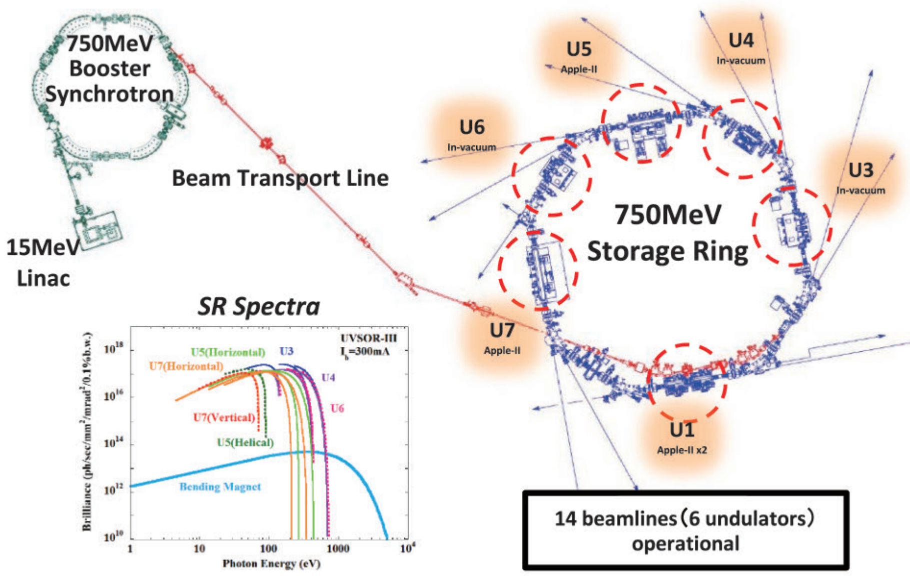
History



1975: Institute Established
1983: First Light
1984: User Operation Start
2003: Upgrade to UVSOR-II
2007: Full Energy Injection Start
2008: Top-Up Test Operation Start
2010: Full Top-Up Operation Start
2012: Upgrade to UVSOR-III

Beamlines at UVSOR-III

Beamline	Optics	Energy Range	Target	Technique
BL1B	Martin-Puplett FT-FIR	0.5-30 meV	Solid	Reflection Adsorption
BL6B	Michelson FT-IR	4 meV-2.5 eV	Solid	Reflection Adsorption
BL7B	3-m normal incidence	1.2-25 eV	Solid	Reflection Adsorption
BL3B	2.5-m off-plane Eagle	1.7-31 eV	Solid	Reflection Absorption
BL5B	Plane grating	6-600 eV	Solid	Calibration Absorption
BL2B	18-m spherical grating (Dragon)	23-205 eV	Solid	Photoionization Photodissociation
BL4B	Varied-line-spacing plane grating (Monk-Gillieson)	25 eV-1 keV	Gas Liquid Solid	Photoionization Photodissociation XAFS / XMCD
BL2A	Double crystal	585 eV-4 keV	Solid	Reflection XAFS
BL1U	Tandem undulators/ Free electron laser	1.6-13.9 eV	Gas Solid	Laser Compton Scattering Orbital Momentum Light
BL7U	10-m normal incidence (modified Wadsworth)	6-40 eV	Solid	Photoemission
BL5U	Varied-line-spacing plane grating (Monk-Gillieson)	20-200 eV	Solid	ARPES Spin-resolved ARPES
BL6U	Variable-included-angle-varied-line-spacing plane grating	40-700 eV	Solid	ARPES XAFS XPD
BL4U	Varied-line-spacing plane grating (Monk-Gillieson)	50-700 eV	Gas Liquid Solid	XAFS Microscopy (STXM)
BL3U	Varied-line-spacing plane grating (Monk-Gillieson)	60-800 eV	Gas Liquid Solid	XAFS Photoemission Photon-emission



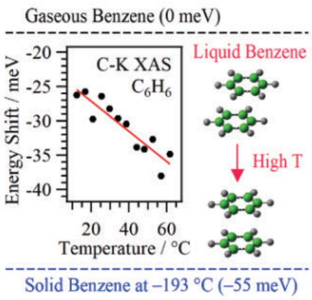
UVSOR-III Synchrotron

Current Activities

When the UVSOR-I ring was built as a second-generation SR facility of standard size, there were only a few large-scale facilities around the world. The UVSOR-I Synchrotron with more than 20 end stations served many different types of experiments in the IR/ FIR, VUV, and soft X-ray (up to 4 keV) regions and accommodated rapidly expanding user community. Molecular science has grown as an interdisciplinary science, combined with meso- and nano-scale spectroscopic approaches covering not only chemical and physical sciences, but also biosciences. Molecular science is now one of the most important research areas for low emittance SR. Since Japan now has 8 SR facilities, the UVSOR-III Synchrotron, as a relatively small third-generation SR facility, can focus on specific applications in advanced molecular science, predominantly using the 6 undulator beamlines. To support its strategic international collaboration program in molecular science, the UVSOR continues to improve and upgrade its micro- and nano-scale photoabsorption and photoemission capabilities and in situ/operando measurements in the VUV and soft X-ray regions.

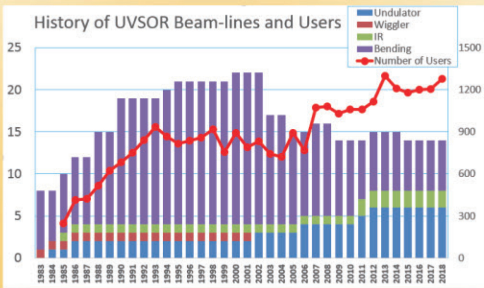
In situ/ *Operando* Soft X-ray Spectroscopy of Liquid

Unexpected temperature-dependent structural changes in liquid benzene



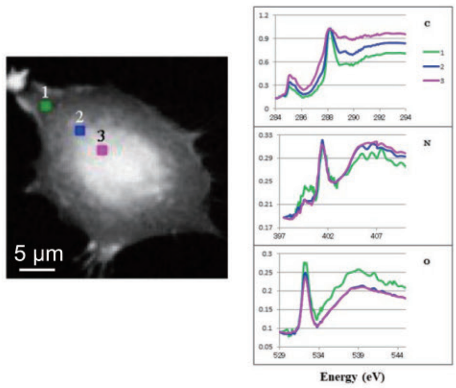
M. Nagasaka *et al.*, *J. Phys. Chem. Lett.* (2018).

36-40 weeks operation / year
Total over 1200 users / year



UVSOR-I (1983 - 2003)　UVSOR-II (2003 - 2012)　UVSOR-III (2012 -)

Quantitative Distributions of DNA, RNA, Histone and Proteins in Mammalian Cells



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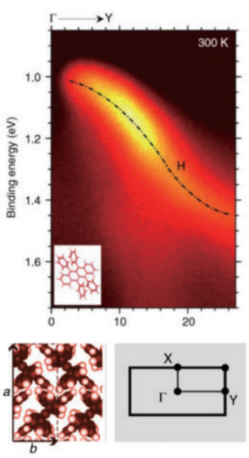
Electronic Structure of Solids and Molecules



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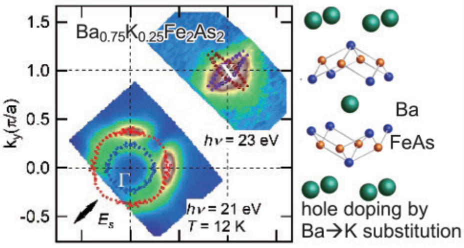

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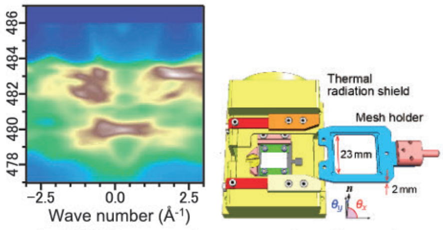

Au(111) by acceptance-cone tunable analyzer

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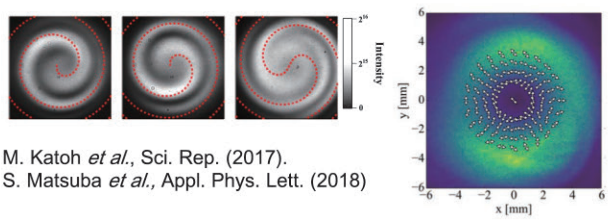
Spatiotemporal Structure of Undulator Radiation and Application to Molecular Science



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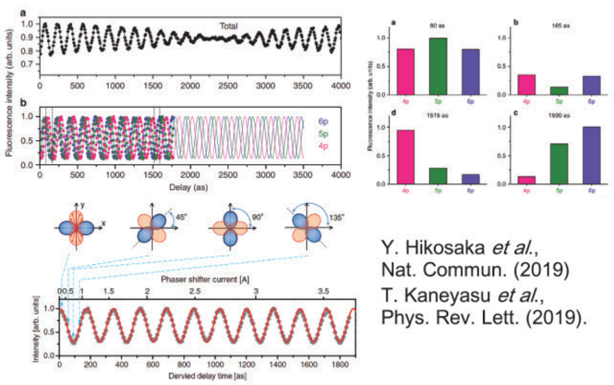

Y. Hikosaka *et al.*, Nat. Commun. (2019)
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Photon Factory (PF) & PF-AR

General Information

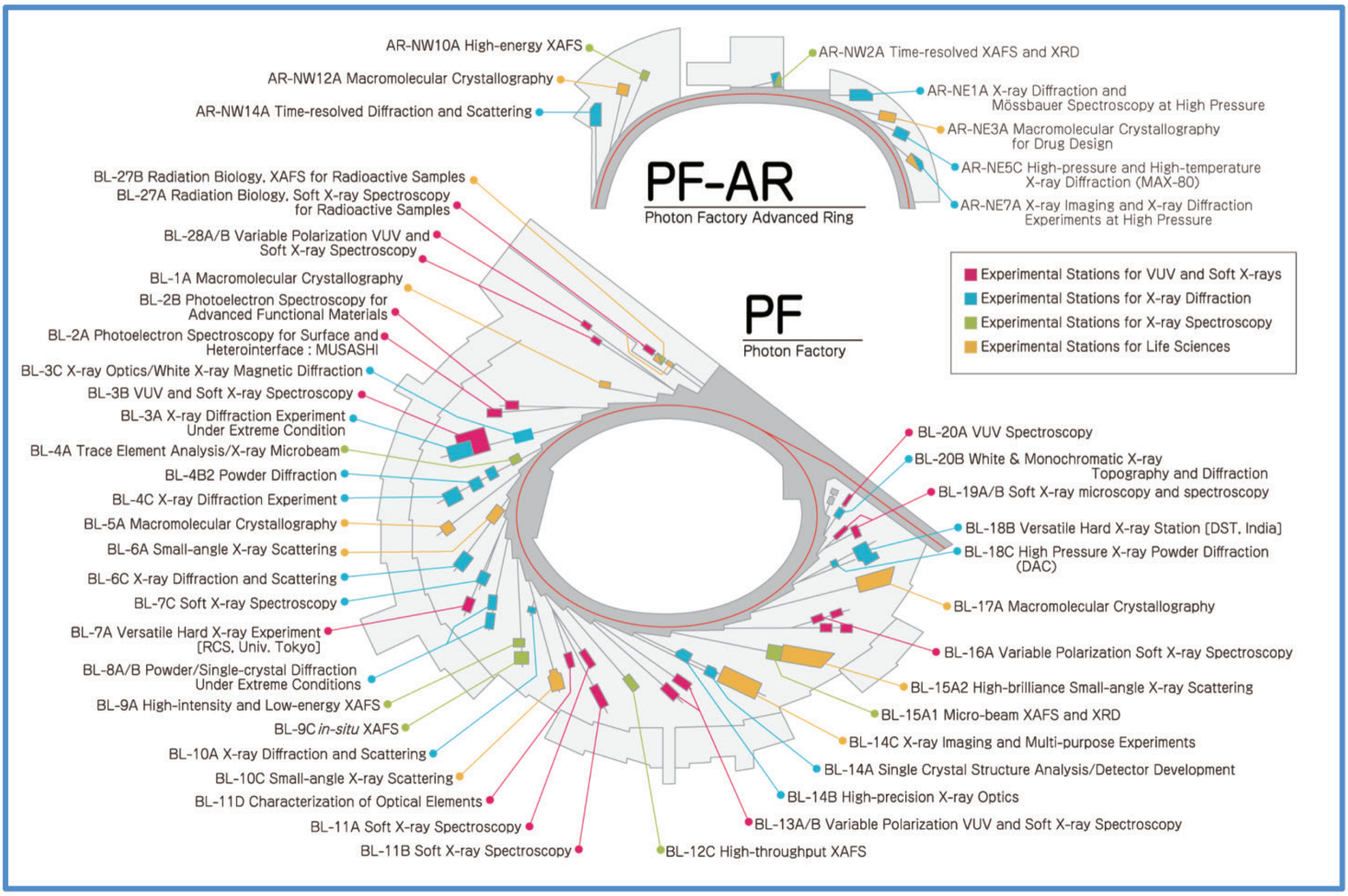
The Photon Factory (PF) is an accelerator-based light source facility in the Institute of Materials Structure Science (IMSS), High Energy Accelerator Research Organization (KEK), located in Tsukuba, Japan. The facility operates two storage rings: the 2.5-GeV PF Ring and the 6.5-GeV PF Advanced Ring (PF-AR).

The 2.5-GeV PF ring was Japan's first synchrotron radiation source to be dedicated for research using hard X-ray beams. Since construction of the first beam line in March 1982, the facility has enabled a substantial amount of scientific research (around 18,000 publications to-date) and hosted many researchers from the international synchrotron radiation community.

The 6.5-GeV PF-AR, which was originally the booster synchrotron for the TRISTAN electron-positron collider, now operates as a dedicated synchrotron light source. PF-AR is uniquely operated in single-bunch mode, making it suitable for experiments that utilize the pulsed nature of synchrotron radiation such as time-resolved experiments.

Each year, PF accepts about 800 proposals and hosts around 3000 users. The facility has 47 beam lines (BLs) as shown below: 39 BLs at PF, and 8 BLs at PF-AR. Some bending magnet BLs are branched to 2 or 3 end stations, which can be used simultaneously. Since the user beam time of PF was recently limited to around 3000 hours per year, most of the insertion device BLs are oversubscribed, including the world's first in-vacuum undulator beam line, AR-NE3A.

For more information about research at PF, please visit the "PF Highlights" website:
https://www2.kek.jp/imss/pf/eng/science/publ/pfhl/



Photon Factory (PF) & PF-AR

Current Activities

Academic Research and Education

As part of KEK, which is one of the Inter-University Research Institute Corporations, the PF storage ring facility supports mainly academic users. Users from a wide variety of fields including physics, chemistry, materials, biological and medical sciences, have utilized PF for leading-edge research. Although the beam brightness from the PF storage ring is now relatively low compared to other state-of-the-art storage rings, the stability of ring operations and the user-friendly nature of the beam lines still offer advantages. In fact, the PF publication database includes more than 10 publications featuring Nobel Prize laureates as authors. PF also supports many graduate students for their masters and PhD program research.

National Projects

PF is contributing to a wide variety of national projects, such as the Elements Strategy Initiative, the Basis for Supporting Innovative Drug Discovery and Life Science Research (BINDS), and the Cross-Ministerial Strategic Innovation Program (SIP).

International Collaborations

PF has been collaborating with international organizations since the early 1980s, including successful operation of beam lines in Australia and India. The Australian National beam line, BL-20B, was built by the Australian Nuclear Science and Technology Organization (ANSTO) and operated from 1992 to 2013. The Indian beam line, BL-18B, was leased from PF to India's Department of Science and Technology (DST), and has been operational since 2009.

Nobel Prize-related research conducted at PF

Hideki Shirakawa

The Nobel Prize in **Chemistry 2000** was awarded *"for the discovery and development of conductive polymers"*. Prof. Shirakawa joined a collaboration at PF to characterize conductive polymers utilizing the EXAFS technique.

EXAFS study of conductive polymers[1)]

Ada E. Yonath

The Nobel Prize in **Chemistry 2009** was awarded *"for studies of the structure and function of the ribosome"*. Professor Yonath frequently came to PF from the Weizmann Institute of Science in Israel to collect data with PF's large-scale Weissenberg camera.

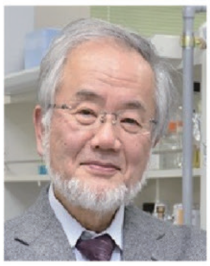
Structural analysis of ribosome[2)]

Isamu Akasaki & Hiroshi Amano

The Nobel Prize in **Physics 2014** was awarded *"for the invention of efficient blue light-emitting diodes"*. The diode samples were measured and characterized at PF with colleagues from Nagoya University.

CTR scattering study of AlN and GaN thin films[3)]

Yoshinori Ohsumi



The Nobel Prize in **Physiology or Medicine 2016** was awarded *"for the discoveries of mechanisms for autophagy"*. Some key proteins of autophagy were crystallized and their structures were determined using both PF and SPring-8.

Structural analysis of autophagy-related ptoteins[4)]

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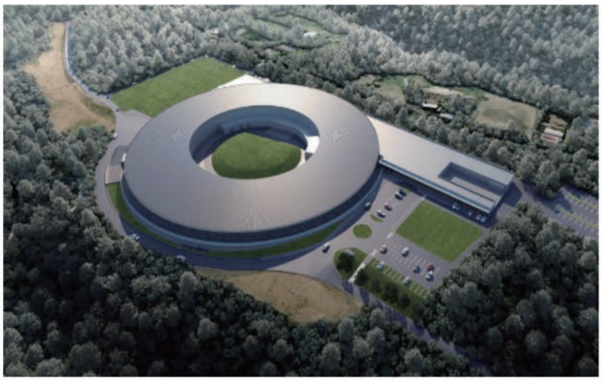
Next Generation 3GeV Facility Project in Japan (SLIT-J)

General Information

The concept for SLiT-J (Synchrotron Light in Tohoku, Japan), a low emittance 3 GeV synchrotron radiation facility, was originally conceived in 2012. In 2018, Japan's Ministry of Education, Culture, Sports, Science and Technology (MEXT) initiated the Next Generation 3 GeV Facility Project on the campus of Tohoku University. Construction and operation of the facility will be carried out by a public–private regional partnership of the National Institute of Quantum Radiological Science & Technology (QST), Tohoku University, Miyagi Prefecture, Sendai City; the Tohoku Economic Federation; and the Photon Science Innovation Center (PhoSIC). Funding comes from a combination of private sector investments, local governments, and MEXT through QST (the National Institutes for Quantum and Radiological Science and Technology)



Rendering of the facility

Light Source

Nanoscopic science and industrial R&D require a brilliant and high coherence light source covering the energy levels of the outer-shell electrons in major elements (i.e., X-rays with energy levels ranging from 50 eV to 30 keV). To meet this demand, the light source for SLiT-J has been designed as a low-emittance 3 GeV synchrotron storage ring using state-of-the-art accelerator technology currently available in Japan. The initial design of the storage ring was based on a double-double bend achromat. The final design of the storage ring consists of 16 cells of a 4-bend achromat lattice, in which each cell has 4 bending magnets (Fig.2, Table I). The facility is designed to save energy by making the devices and equipment as compact as possible.

Lattice parameter

Beam energy	E (GeV)	2.998
Lattice structure		4bend achromat
Circumference	C (m)	348.8432
Number of cells	N_s	16
Long straight section	(m)	5.4400 × 16
Short straight section	(m)	1.6427 × 16
Betatron tune	x / y	28.17 /9.23
Natural chromaticity	x / y	-60.50 / -40.99
Natural horizontal emittance	(nmrad)	1.14
Momentum compaction factor	α	0.000433
Natural energy spread	$\sigma E/E$ (%)	0.0843
Lattice functions at LSS	$\beta_x / \beta_y / \eta_x$ (m)	13.0 / 3.0 /0.0
Lattice functions at SSS	$\beta_x / \beta_y / \eta_x$ (m)	4.08 / 2.962 /0.052
Damping partition number	J_x / J_s	1.389 /1.611
Damping time	$\tau_x / \tau_y / \tau_s$ (ms)	8.091 / 11.238 /6.976
Energy loss in bends	(MeV/turn)	0.621
RF frequency	(MHz)	508.75905
Harmonic number	h	592
Beam size at long straight	σ_x/σ_y	121/5.8

Main parameters for the light source

End Stations

A maximum of 26 beam lines can be installed in the storage ring. 7 to 10 beam lines will be available when the facility opens, with additional beam lines installed in the future to meet scientific demands. The facility will include two types of end-station (ES): automated measurement stations and advanced measurement stations. The automated measurement stations will enable high-throughput routine measurements by making full use of robot and IT technology along with brilliant X-rays. The advanced measurement stations will enable users to make customized measurements under various conditions and environments by installing their own custom-developed instruments in the end-station using a standardized plug-in system. Furthermore, the plug-in system will allow users to perform measurements utilizing multiple beamlines.

The first ten beamline lineups have been suggested by the QST/PhoSIC Beamline Design Committee to meet the following criteria: 1) effective use of the low-emittance light source; 2) the needs of both academia and industry; and 3) complementary capabilities with other facilities in Japan.

Two types of end-station in SLiT-J

Coalition Concept

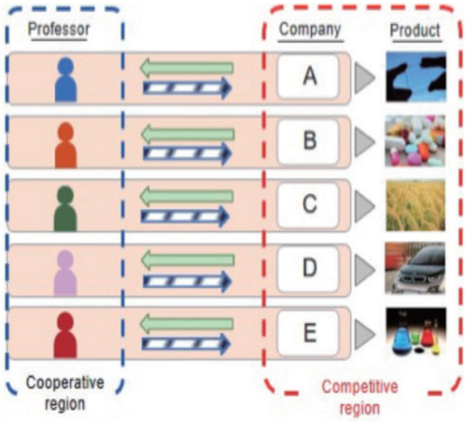
New Approach to Drive Innovation

"Coalition Concept", a new industry-academia alliance scheme

A key objective of SLiT-J is to promote interdisciplinary alignment between industrial R&D applications and academic research applications: SLiT-J can alternatively be called as Super Lightsource for Industrial Technology in Japan. Industrial users require a practical and demand-oriented user-support system staffed with relevant experts. At the same time, competition for resources among industrial companies must be managed. The Coalition Concept is a new approach where academic researchers can provide one-on-one collaborative support for a company that is providing funding for construction of SLiT-J.

The academic coalition partners will support the SR research of their industrial partners by sharing R&D objectives for SR experiments and assisting with data analysis. Industry's main concerns with this scheme are preventing technology leaks and protecting industrial technology. The key to addressing these risks is to implement a demarcation line separating the "cooperative zone" from the "competitive zone" for SR usage. An alternative solution would be to systemize analysis companies as coalition partners. This "Coalition Concept" has been attracting industrial users for advanced utilization of the SR facility, which we believe will lead to organizational structures that address the concerns of industrial companies while promoting the diversity of SR research.

"Coalition Concept"
One-to-one collaborative support from academic researchers



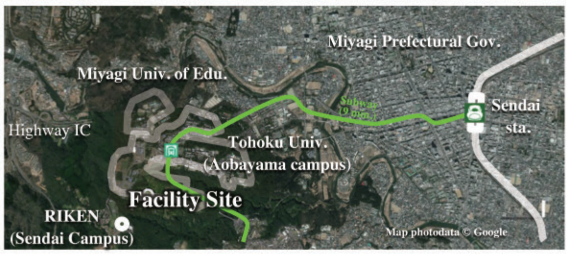
Support facilities' technology on measurement & analysis methods

・Product development
・Develop the product concept

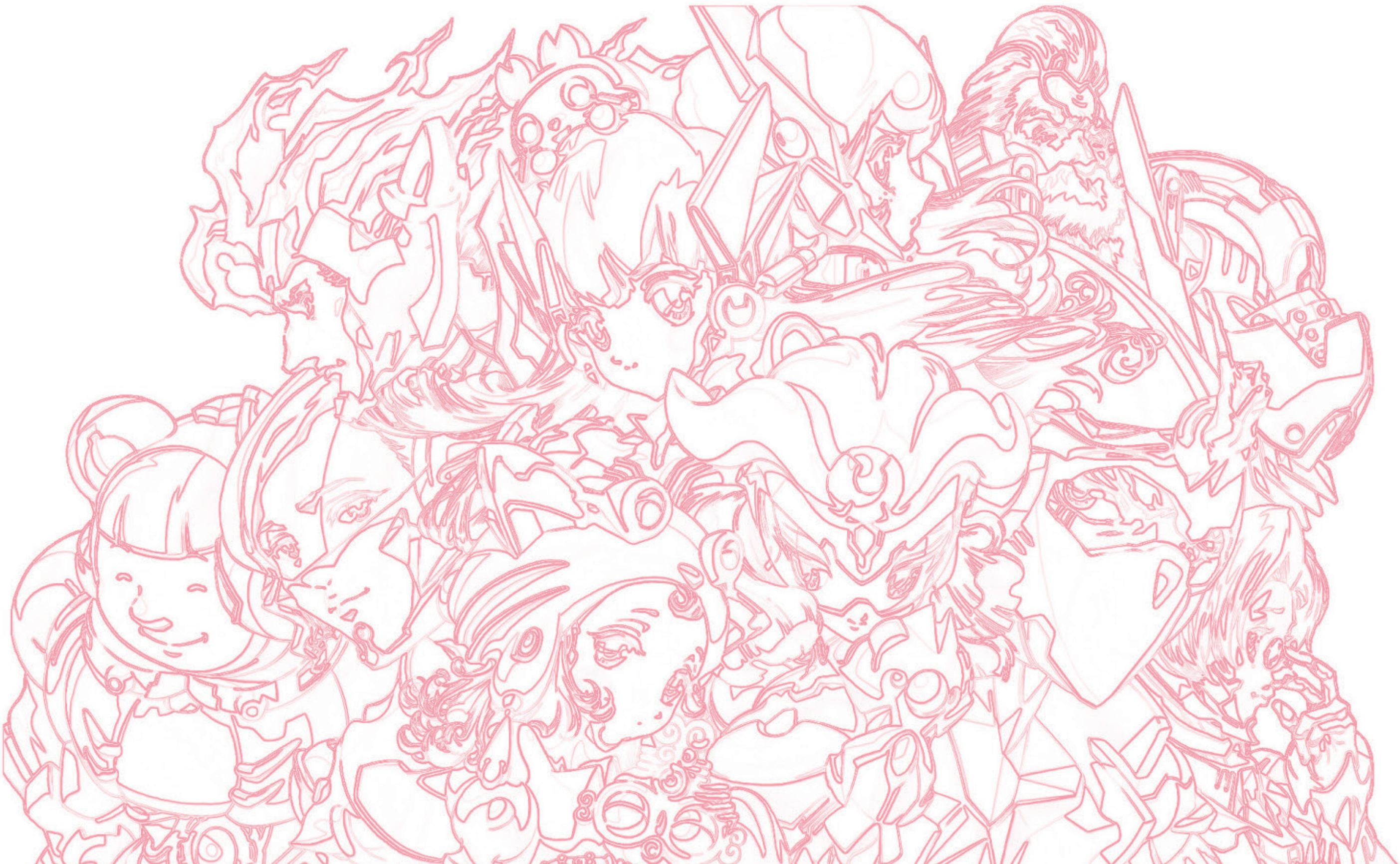
Current Activities

The history and current status of the project is as follows:

1. The "SLiT-J International Evaluation Committee" for the The Concept Design Report version 2.1. (CDR 2.1) was held in June 2016.
2. An open design competition for the SLiT-J end-stations was held in July 2017 to gather insights from Japanese experts.
3. A general incorporation foundation, the "Photon Science Innovation Center" (PhoSIC), was established to receive investments from the private industrial sector for the SLiT-J project in December 21, 2017.
4. The SLiT-J user community was launched in January 7, 2017.
5. PhoSIC requested permission to use a part of Tohoku University's Aobayama campus for SLiT-J.
6. Deliberation on using synchrotron radiation as a source for soft X-rays and its usage began in November 2016 at the committee in Japan's Ministry of Education, Culture, Sports, Science and Technology (MEXT).
7. MEXT initiated construction of the new 3 GeV facility on the campus of Tohoku University.



The site preparation work started in March of 2019 and the first beam is to be operational in 2023.



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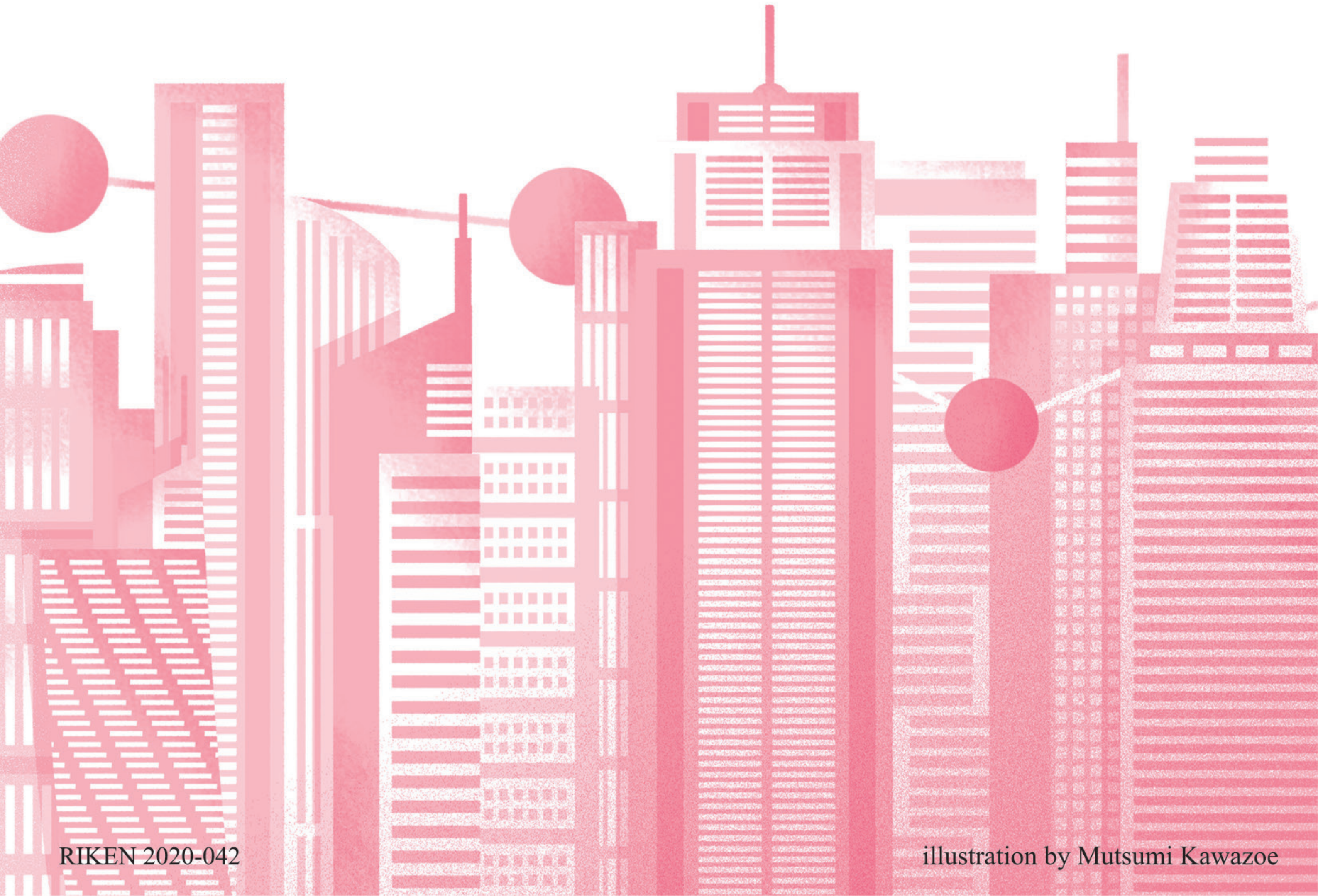

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illustration by Mutsumi Kawazoe