國家同步輻射研究中心
National Synchrotron Radiation Research Center

NSRRC

Synchrotron Light Source

The evolution of light sources echoes the progress of civilization in technology, and carries with it mankind's hopes to make life's dreams come true.

The synchrotron light source is one of the most influential light sources in scientific research in our times.

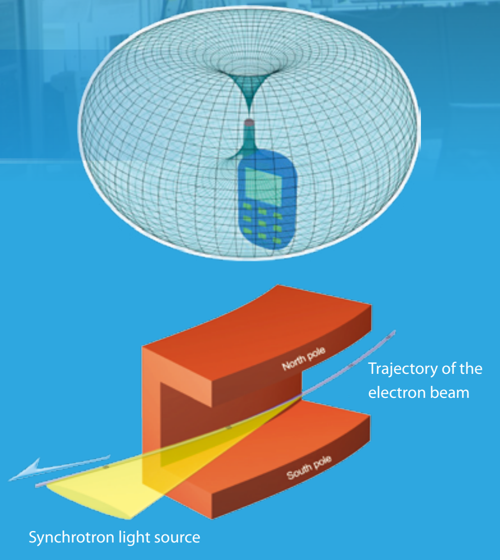
Bright light generated by ultra-rapidly orbiting electrons leads human beings to explore the microscopic world.

Located in Hsinchu Science Park, the NSRRC operates a high-performance synchrotron, providing X-rays of great brightness that is unattainable in conventional laboratories and that draws NSRRC users from academic and technological communities worldwide. Each year, scientists and students have been paying over ten thousand visits to the NSRRC to perform experiments day and night in various scientific fields, using cutting-edge technologies and apparatus. These endeavors aim to explore the vast universe, scrutinize the complicated structures of life, discover novel nanomaterials, create a sustainable environment of green energy, unveil living things in the distant past, and deliver better and richer material and spiritual lives to mankind.

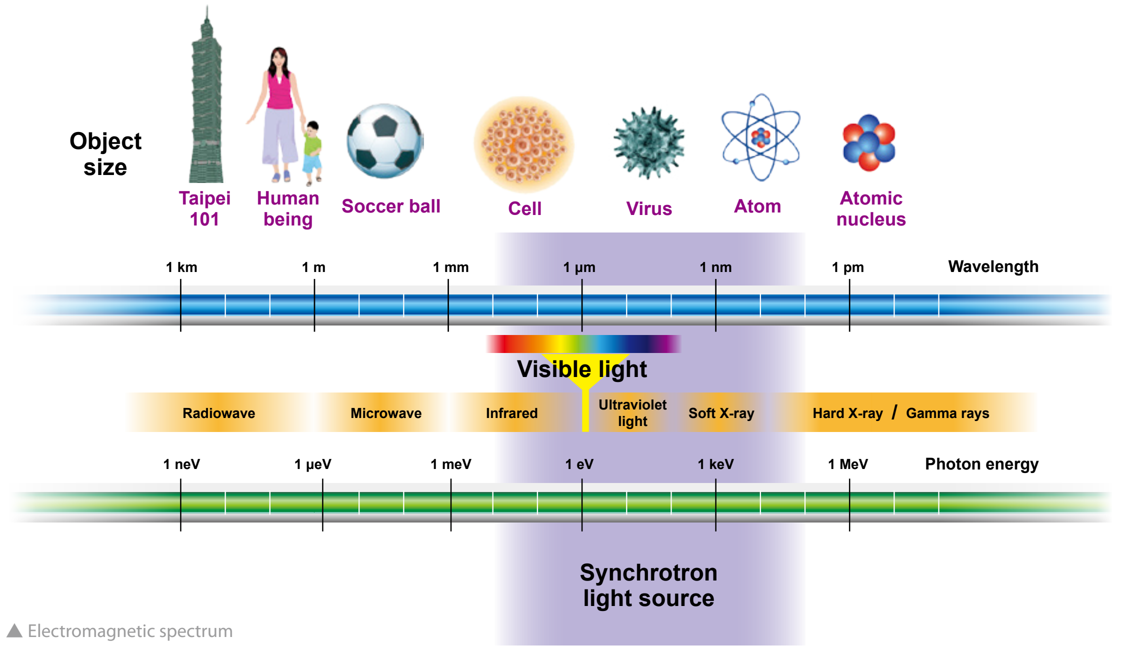
Synchrotron Light Source

Light, also known as electromagnetic waves, has always been an important means for humans to observe and study the natural world. The electromagnetic spectrum includes not only visible light, which can be seen with a naked human eye, but also radiowaves, microwaves, infrared light, ultraviolet light, X-rays, and gamma rays, classified according to their wave lengths. Light of varied kind, based on its varied energetic characteristics, plays varied roles in the daily lives of human beings.

The synchrotron light source, accidentally discovered at the synchrotron accelerator of General Electric Company in the U.S. in 1947, emits electromagnetic waves of a continuous spectrum from beyond infrared light through visible light and ultraviolet light to X-rays. Light from a synchrotron features great brilliance, a small cross section, and a wavelength continuity ranging from tens of micrometres to hundredths of a nanometer. As such it can help humans to explore the world invisible to a naked eye.



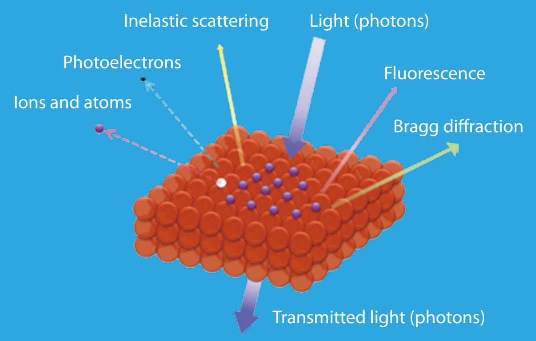
▲ Unlike a mobile phone that radiates radio waves in all directions, electromagnetic waves are emitted in the direction tangential to the electron trajectory when electrons execute a circular motion at nearly the speed of light, through a relativistic effect.



▲ Electromagnetic spectrum

Synchrotron light source – the best sharp tool for scientific experiments

Varied phenomena, such as emission of photoelectrons; desorption or ablation of ions or atoms; absorption, scattering or diffraction of photons; and fluorescence, occur when matter is irradiated with light from a synchrotron. Each such phenomenon is closely related to the physical or chemical characteristics of the material. Studying a material with light from a synchrotron thus enables a precise exploration of the inner structure of a material, and the electron-electron interactions therein. The synchrotron light source is an indispensably sharp experimental tool for cutting-edge research in basic science, biomedical technology and industrial applications in the twenty-first century. It is applied broadly to diverse fields such as material science, biology, medicine, physics, chemistry, chemical engineering, geology, archeology, environmental protection, energy science, electronics, micromachining and nanotechnology.

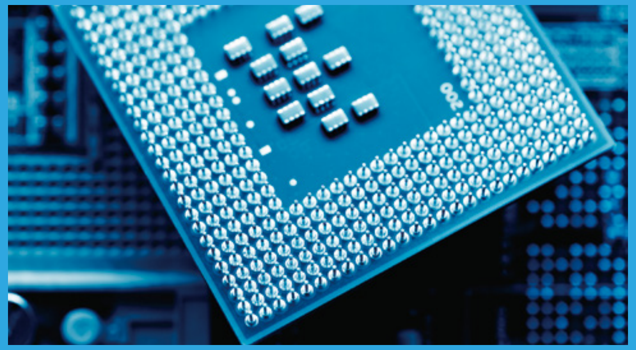


Applications of the Synchrotron Light Source

Discovery of novel materials

Inspecting the microstructures of materials with synchrotron light of small wavelength and great brightness is an important way to reveal the properties of materials and to innovate in material applications. Synchrotron light coupled with advanced microscopic and spectroscopic techniques is an important experimental method to discover novel materials and to study structures on a nanometer, or even smaller, scale.

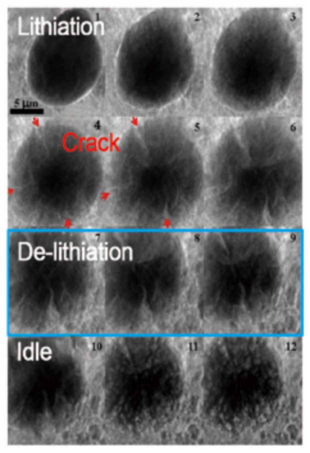
Taking research on high-T_c superconductors as an example, physicists can apply synchrotron light to explore the mechanism of superconductivity, or to search for new superconductors with zero electrical resistance even at room temperature. Taking electronic fabrication as another example, when the sizes of electronic storage devices are shrunk gradually down to a nanometer scale, the characteristics of the surface atoms become increasingly important. Research using synchrotron light is capable of revealing significant information such as nanoscale electronic and atomic structures of matter to facilitate the discovery of superior materials. This work aids tremendously to increase the storage capacities and the processing speeds of electronic components.



Development of green energy

In recent years, man-made chemicals and air pollution produced by human activities have seriously altered the condition of the terrestrial atmosphere. In particular, the anthropogenic greenhouse effect of carbon dioxide, emitted by burning fossil fuels, has resulted in global warming and climate change. Mother Nature, ecology, human health, economy, as well as the human society are faced with unprecedented severest challenges ever.

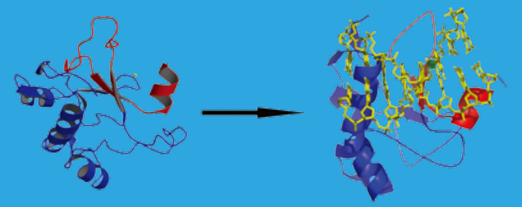
Scientists have been searching actively for highly efficient and clean energy sources. A lithium-ion battery, a rechargeable battery, is one green energy product with little pollution, in which lithium ions move between the anode and the cathode, during which chemical energy is converted to electrical energy. Using a transmission X-ray microscope with spatial resolution 50 nm at the NSRRC, researchers monitored the microscopic images of the electrodes, and investigated the changes of particles of tin, nickel, manganese or other materials of the cathode in real time during the charge-discharge cycle (migration of lithium ions in and out), so as to learn the sizes, shapes and distributions of internal grain structures in the process. This work will help scientists to discover novel materials with increased efficiencies and prolonged service lives for a lithium-ion battery in the future.



Exploring the mysteries of life

From the discovery of the DNA structure to the decoding of its genes, scientists have been exploring the mysteries of life using modern biotechnologies. Through the understanding of complex life forms, they hope to produce new opportunities for drug discovery and improvements in agriculture and fishery.

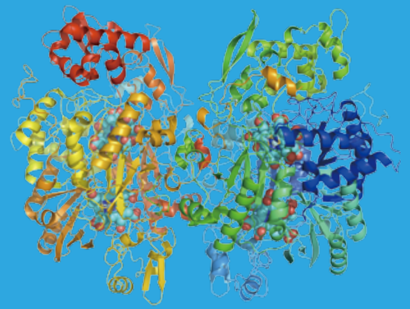
Proteins are essential parts of various enzymes, hormones and antibodies within living organisms, but they are also major components of life-threatening viruses. Proteins, comprising chains of amino acids, are large biological molecules with complicated structures. Each protein, consisting of amino acids in a unique sequence and folding to a specific three-dimensional structure, possesses a specific function to fulfill a particular mission. The unique three-dimensional structure of a protein is thus pivotal information for an understanding of the interactions of the protein with other molecules. Protein crystallography has grown exuberantly into an important experimental technique for life science in recent years. Using synchrotron X-rays of great brightness and energy tunability, researchers are able to reveal individual atomic positions in a vast 3D protein structure, on performing diffraction experiments on a protein crystal. Through the building up of a comprehensive database of numerous protein structures, we hope to understand the phenomena and mechanisms of life, to discover diagnostic and treatment methods of diseases, to improve the efficiency of agriculture, to perform selective breeding, and to develop new biotechnologies.



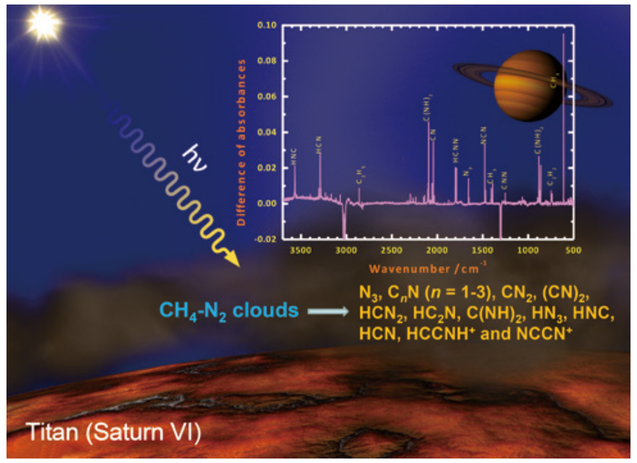
A protein structure

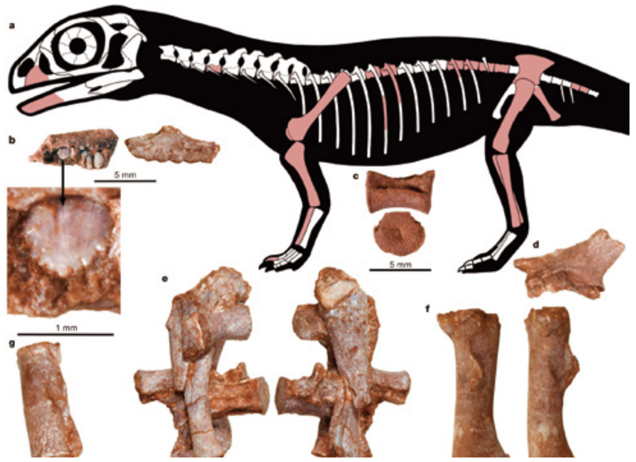
Interaction of a protein with a DNA

▲ Interactions between proteins and nucleic acids are the linchpin to reveal how living things operate. The synchrotron light source enables one to probe the binding between proteins and DNA.



▲ Intricate configurations of protein complexes and cofactors play important functional roles such as in enzyme catalysis and metabolism. Utilizing a synchrotron light source, researchers were able to map the structure of an enzyme crucial to the germination of rice, and the structure of a vital electron-transfer and redox enzyme in an esoteric bacterium.





Unveiling the secrets of the cosmos

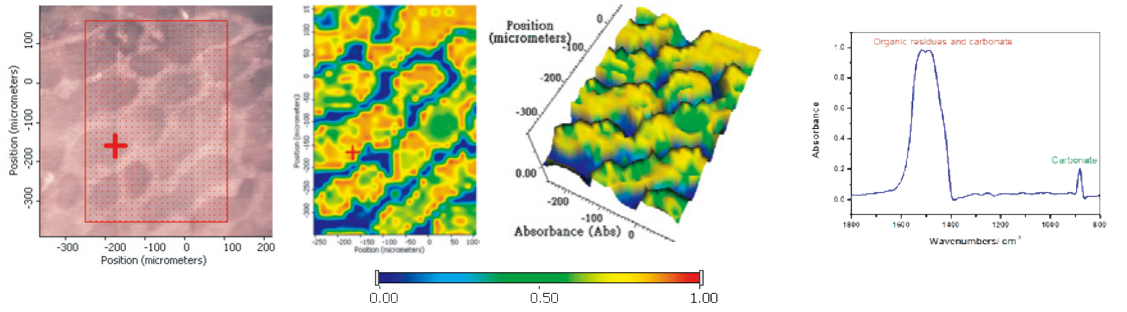
How did the universe originate? How were celestial bodies formed? For centuries scientists have been trying to find out the answers. Vacuum ultraviolet (VUV) light is an important driving force for the evolution of life in the solar system or elsewhere in space. Interstellar molecules of more than 160 kinds are formed through photolysis and chemical reactions. Using VUV light and advanced experimental techniques, researchers are able to explore the photophysical and photochemical characteristics of interstellar molecules.

Using synchrotron VUV light as an excitation source, one can photolyze and dissociate important interstellar molecules (such as a mixture of nitrogen and methane) under cryogenic conditions mimicking those in interstellar space, and then analyze the ensuing fragments and products with an IR spectrometer. These investigations afford us a profound understanding of the evolution and chemical transformations of interstellar molecules. Moreover, using synchrotron VUV light instead of electrons to ionize and to probe the reaction products of a crossed-molecular-beam experiment can decrease greatly the chance of further dissociation of the reaction products, thus preserving their identities. This advance will help us to understand the mechanisms of formation of larger hydrocarbons in interstellar matters.

Identification of lives in the distant past

The modi vivendi of paleontologic lives are mysteries scientists have been hankering to unveil. Using synchrotron infrared spectromicroscopy, with a spatial resolution no conventional infrared light can match, scientists studied fossils of bones at various stages of embryonic development of a species of dinosaurs that lived 195 million years ago during the Early Jurassic epoch. They found spectroscopic evidence of organic chemical bond moieties and obtained their detailed concentration maps in the bone cross sections. This is the oldest evidence of *in situ* preservation of complex organic remains in a terrestrial vertebrate.

The mere fact that organic residues can be found in fossils 195 million years old is both astounding and encouraging, and it could have reverberating ramifications. Scientists are trying to push the boundary further to fuller identification of the compositions of these organic matters beyond chemical bond moieties, in the hope that they will divulge more secrets about these creatures.



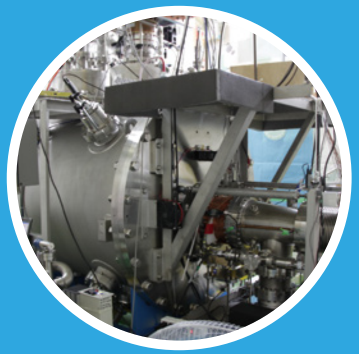
▲ An infrared spectrum of organic residues and their distribution images of a dinosaur embryo fossil from the Early Jurassic epoch. Results were published in Nature **496**, 210 (2013).

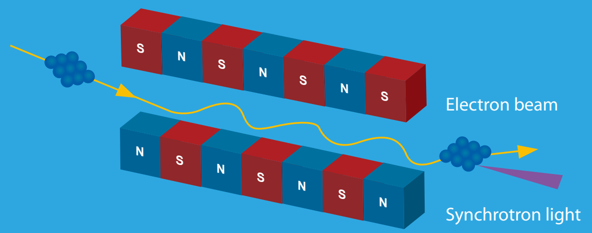
Magnetic system of the TPS accelerator

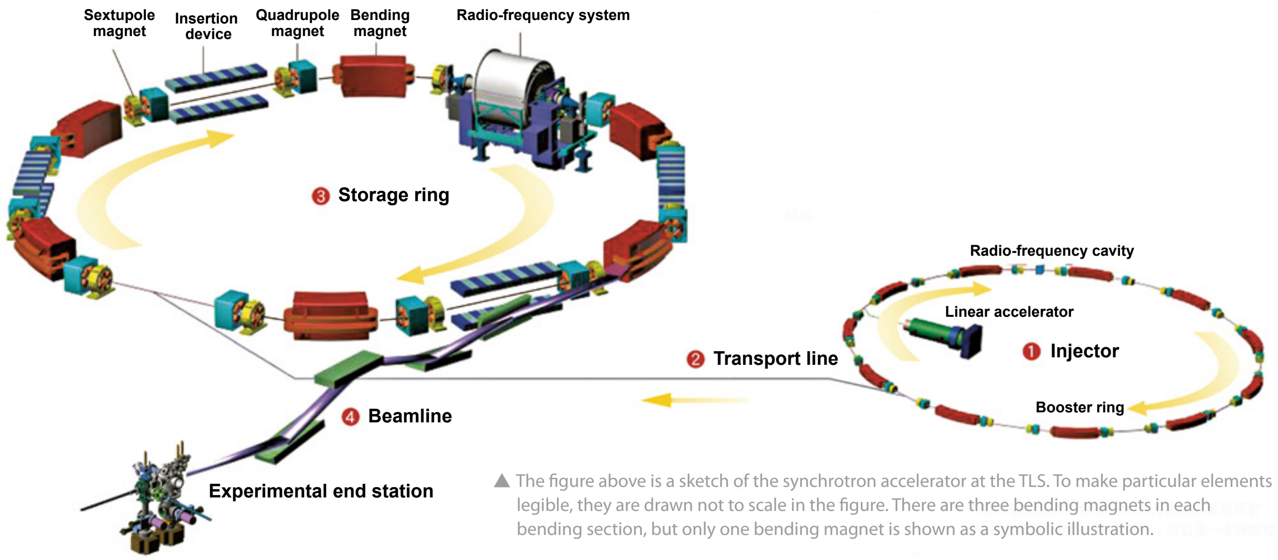
How is Synchrotron Light Produced?

Based on the theory of electricity and magnetism, charged particles emit electromagnetic waves whenever their speed or direction of motion is altered. When electrons, traveling near the speed of light, are deflected with a magnetic field, they radiate a collimated beam of electromagnetic radiation centered in a direction tangential to their trajectory, through a relativistic effect. This light is known as synchrotron light.

Taking the accelerator of the NSRRC, the Taiwan Light Source, as an example, electrons emitted from an injector (❶) are injected into a storage ring (❸) through a transport line (❷). Synchrotron light is produced when electrons pass through bending magnets or insertion devices, such as undulators and wigglers, in the storage ring. The light is then channeled through beamlines (❹) to experimental stations at which scientists perform their experiments.







▲ The figure above is a sketch of the synchrotron accelerator at the TLS. To make particular elements legible, they are drawn not to scale in the figure. There are three bending magnets in each bending section, but only one bending magnet is shown as a symbolic illustration.

❶ Injector (LINAC and booster ring)

Electrons produced with an electron gun are accelerated with a linear accelerator (LINAC) to an energy of 50 million electron volts each. Electrons then enter a booster ring of circumference 72 meters and are accelerated further to 1.5 billion electron volts each, reaching a speed of 99.999995 percent of the speed of light in vacuum.

❷ Transport line

Electrons generated from the injector pass through the transport line and enter the storage ring. The length of the transport line is 70 meters.

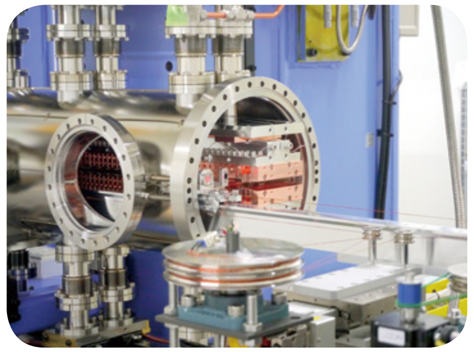
❸ Storage ring

Upon entering the hexagonal storage ring of circumference 120 meters, electrons are steered with bending magnets in a series and are maintained in a closed orbit. Synchrotron light is produced whenever electrons travel through a bending magnet or an insertion device within each loop. To compensate for the loss of energy of the electrons due to emission of synchrotron light, a radio-frequency (RF) cavity is installed to replenish their energies.

❹ Beamline

A beamline serves as a link between the synchrotron light source and an experimental end station. In principle, at each bending arc of the electron trajectory and at the downstream side of each insertion device, a port can be opened to release the synchrotron light into a beamline, which directs it to an experimental end station.

Insertion devices - wigglers and undulators

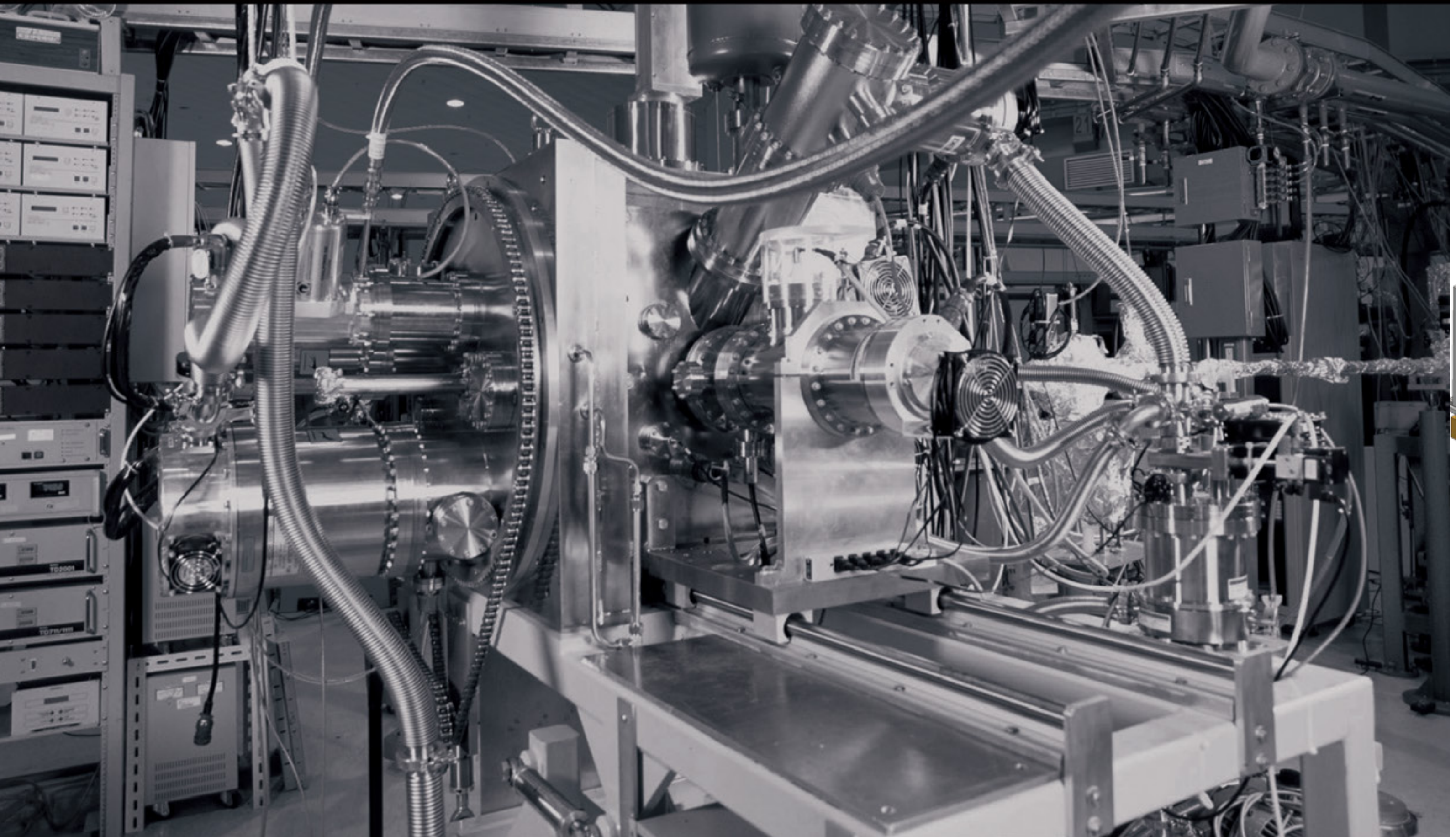


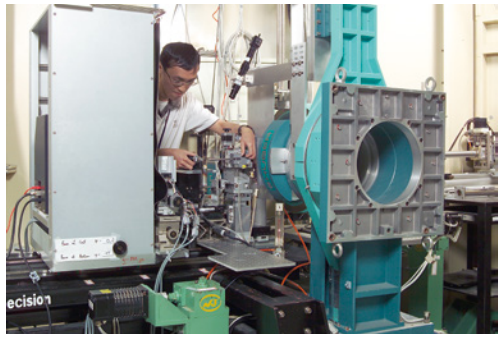
An insertion device comprises magnets in a row or rows with alternating polarities, resulting in a periodic magnetic structure. These magnets deflect the passing electrons multiple times. When the periodic magnetic structure is such that the maximum angular deflection of the orbit is far greater than the central angular width of the synchrotron radiation cone, radiation from separate periods adds incoherently, as if it derives from unrelated bending magnets. This configuration constitutes what has been called a wiggler.

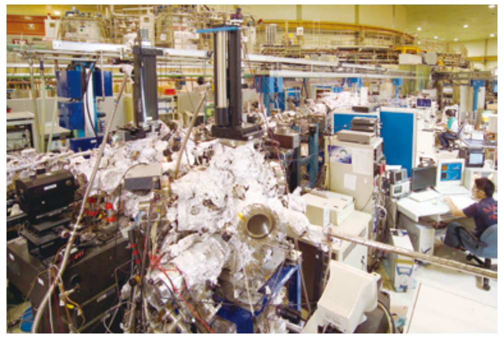
In contrast, if the periodic magnetic structure is such that the maximum angular deflection of the orbit is comparable with or smaller than the central angular width of the synchrotron radiation cone, radiation from separate periods has a chance to overlap spatially and to interfere coherently to produce periodic sharp peaks, known as the fundamental and its harmonics, across the spectrum. A magnetic structure of this configuration is called an undulator. This device can be implemented on having, for example, a short enough magnetic period. As the angular divergence of radiation from an undulator is much smaller than that from a wiggler, an undulator provides much higher brightness than the other one.

Frontier Scientific Research

At the NSRRC, 26 beamlines are operational and are available to scientists to conduct various advanced scientific experiments, which tackle the most trail-blazing topics of science in each research field. To this end, the photon flux, energy resolution, beam size and energy range of each beamline are tailored for specific experimental subjects, along with the corresponding optics and experimental apparatus.





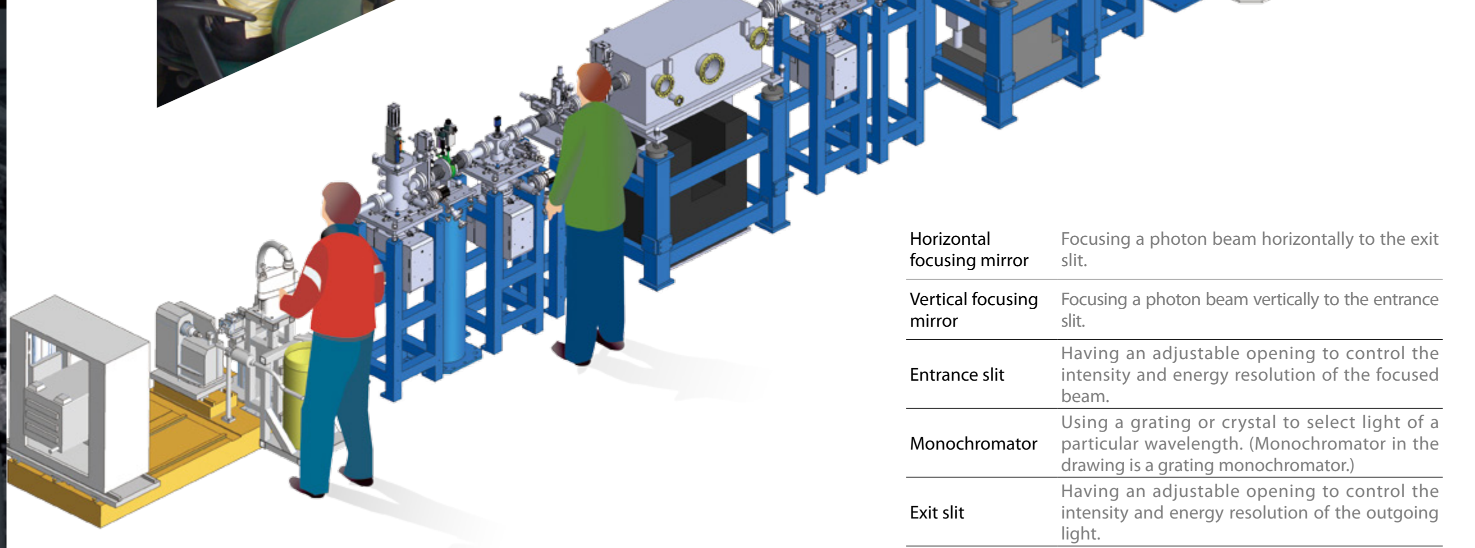


Experimental end stations

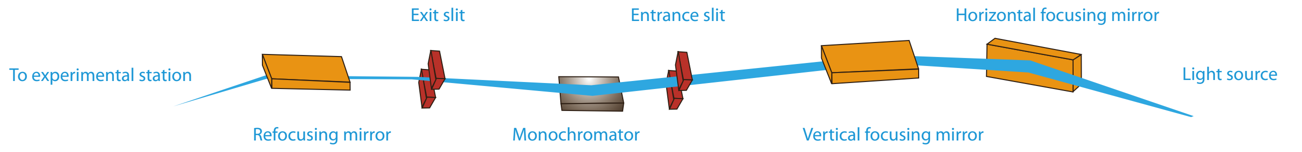
Located at the ends of beamlines are end stations, which, to cater to the specific research subjects and beam properties, are equipped with pertinent, specialized experimental detectors and sample-handling equipment, such as sample-position monitors, optics, diffractometers, and beam-position monitors. When a material is irradiated with synchrotron light, various physical or chemical phenomena of the material occur, such as photoelectron emission, desorption or ablation of ions or atoms, absorption or reflection or transmission or scattering or diffraction of light, or fluorescence. These effects are measured with instruments such as microscopes and spectrometers.

Data analysis

In general, users can take their experimental data to their home laboratory after they have conducted experiments at the beamlines, for analysis at convenience, but online data analysis provides not only data inspection in real time but also instant data analysis and feedback to the experiments. Data collection is at present more rapid, and the amount of data more massive, than ever before. To meet the demand of online data analysis, workstation clusters are provided for large-scale storage and high-performance computing at the NSRRC.



Horizontal focusing mirror	Focusing a photon beam horizontally to the exit slit.
Vertical focusing mirror	Focusing a photon beam vertically to the entrance slit.
Entrance slit	Having an adjustable opening to control the intensity and energy resolution of the focused beam.
Monochromator	Using a grating or crystal to select light of a particular wavelength. (Monochromator in the drawing is a grating monochromator.)
Exit slit	Having an adjustable opening to control the intensity and energy resolution of the outgoing light.
Refocusing mirror	Focusing light to a sample at the experimental station.



Evolution of Synchrotron Light Sources

Synchrotrons have been used primarily by high-energy physicists since the mid twentieth century as indispensable tools to search for fundamental particles and to explore the essence of the cosmos. After the discovery and confirmation of electromagnetic radiation generated by synchrotrons, physicists and chemists began to apply this radiation in their scientific experiments during the hiatus of high-energy research. Such light sources were subsequently described as first-generation synchrotron light sources.

In the 1970s, scientists gradually became appreciative of the advantages of synchrotron light sources. One after another, many developed countries began to build synchrotrons specifically to generate electromagnetic radiation. Such facilities were called second-generation synchrotron light sources.

In the 1980s, new and innovative concepts were proposed by scientists to install insertion devices, such as wigglers and undulators, in a storage ring to deflect electrons multiple times instead of just once in a segment of the storage ring. Such an improvement has increased the brightness of synchrotron light more than a thousand times. In addition, the brightness of the photon beam increases as electrons in the circulating electron beam become more compact in space, their momentum vectors more parallel, and the spread of the momentum magnitudes narrower. Such a spread of electron position and momentum is termed the emittance of the storage ring, which is dictated by the layout of the magnets of the storage ring. A synchrotron designed with a small emittance and an emphasis on insertion devices to provide photon beams of great brightness is known as a third-generation synchrotron light source.

At present, there are nearly 50 operational synchrotron light sources for scientific research around the world. The third-generation synchrotron light sources among these began to open to user experiments in 1994. The Taiwan Light Source of the NSRRC began to be commissioned in 1993, and became the third third-generation soft X-ray synchrotron light source in the world to come on line for user experiments in April, 1994. As the demand for even brighter synchrotron X-rays for advanced research increases, Taiwan has begun to construct a second synchrotron light source, the Taiwan Photon Source (TPS). The project was approved by the government in 2007, and construction began in 2010. On its completion, the TPS is expected to be one of the world's brightest synchrotron light sources.

SPring-8 (8 GeV), Japan

APS (7 GeV), USA

ESRF (6 GeV), France

SSRF (3.5 GeV), China

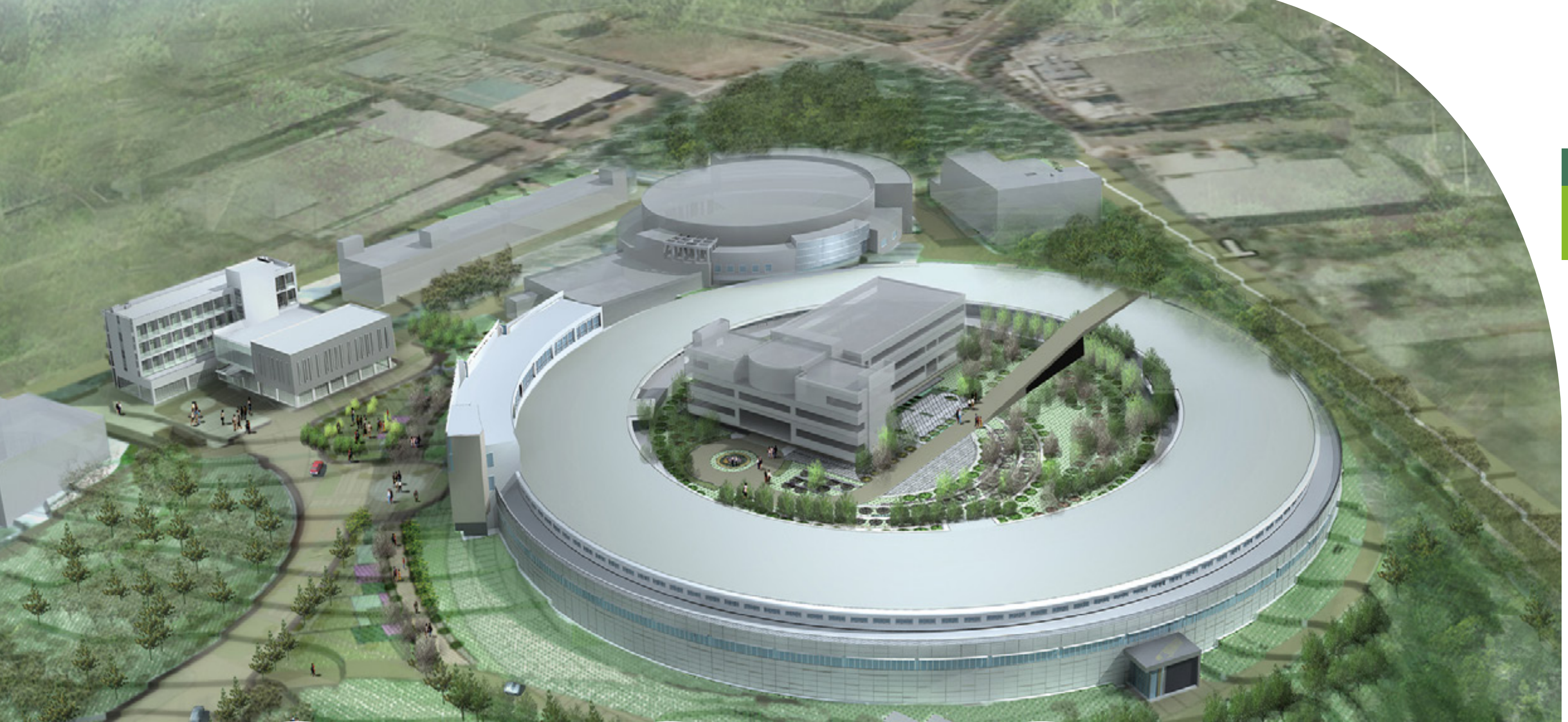
Diamond (3 GeV), UK

SLS (2.4 GeV), Switzerland

Third-generation synchrotron light facilities

Name	Location	Energy	Year of commissioning started
European Synchrotron Radiation Facility (ESRF)	France	6.0	1992
Advanced Light Source (ALS)	USA	1.9	1993
Taiwan Light Source (TLS)	Taiwan	1.5	1993
Elettra Synchrotron Light Source (ELETTRA)	Italy	2.4	1993
Pohang Light Source (PLS)	Korea	2.5	1995
Advanced Photon Source (APS)	USA	7.0	1995
MAX-Lab (MAXII)	Sweden	1.5	1997
Super Photon Ring – 8 GeV (SPring-8)	Japan	8.0	1997
BESSYII Accelerator (BESSYII)	Germany	1.9	1998
Swiss Light Source (SLS)	Switzerland	2.4	2001
Canadian Light Source (CLS)	Canada	2.9	2003
Stanford Synchrotron Radiation Laboratory (SSRL-SPEAR3)	USA	3.0	2004
SOLEIL Synchrotron (SOLEIL)	France	2.75	2005
Diamond Light Source (Diamond)	UK	3.0	2006
Australian Synchrotron	Australia	3.0	2007
Shanghai Synchrotron Radiation Facility (SSRF)	China	3.5	2008
PETRA III at DESY	Germany	6.0	2008
Synchrotron Light Facility (ALBA)	Spain	3.0	2010
National Synchrotron Light Source II (NSLSII)	USA	3.0	2014
Taiwan Photon Source (TPS)	Taiwan	3.0	2014
MAX-IV Laboratory	Sweden	1.5/3.0	Under construction
Sirius: the New Brazilian Synchrotron Radiation Source	Brazil	3.0	Under construction

Unit of energy: GeV



The SRRC Dedication Ceremony in 1993.

The opening ceremony of the protein crystallography facility in 2005.

The ground-breaking ceremony for the TPS in 2010.

From TLS to TPS

The Taiwan Light Source was made available to domestic and foreign researchers in April, 1994. With the gradual completion of attendant experimental facilities, the number of beamlines has increased from 3 to 24 with spectra in a range from infrared to hard X-ray. In addition, the NSRRC owns two Taiwan Contract Beamlines at SPring-8 in Japan. Since the inauguration of the TLS user program, the number of user-runs from users worldwide has been increasing rapidly, and both the quantity and quality of research output have grown significantly, which includes a sizable amount of world-class experiments in many fields. Looking forward to the completion of the Taiwan Photon Source, we hold grand visions of it:

- To make TPS one of the brightest synchrotron light sources in the world, build a world-class interdisciplinary experimental facility, and achieve a leading position in the international community.
- To invent innovative experimental techniques and expand fields of scientific research, especially in biomedicine and nanoscience technologies, to catapult academic research in Taiwan to the top of the world.
- 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 the NSRRC, or to build their exclusive beamlines, and to promote international collaboration to advance Taiwan's international status.
- To be an important incentive for internationally renowned scientists to engage in long-term advanced interdisciplinary research in our country.
- To entice and foster students to devote themselves to advanced research that can lead to scientific discoveries of far-reaching importance.

Milestones

1981	National Science Council established the "Synchrotron Radiation Feasibility Study Group".
1983	The Executive Yuan approved the establishment of the Synchrotron Radiation Research Center (SRRC) and its "Advisory Committee".
1986	"The Preparatory and Construction Office of the Synchrotron Radiation Research Center of the Executive Yuan" was established; a groundbreaking ceremony was held in Hsinchu Science-based Industrial Park.
1993	The "SRRC Dedication Ceremony" was held.
1994	TLS was formally made available to domestic and international users.
1998	SRRC and Japan's SPring-8 synchrotron facility signed a memorandum of collaboration, planning for two Taiwan Contract Beamlines.
2001	Two Taiwan Contract Beamlines at SPring-8 in Japan were completed.
2003	"The Construction Office of the Synchrotron Radiation Research Center of the Executive Yuan" was reorganized as a government-regulated non-profit entity, "National Synchrotron Radiation Research Center" (NSRRC).
2007	The TPS project was approved by the Executive Yuan.
2010	The ground-breaking ceremony for the TPS took place.
2012	Taiwan Neutron Project at the ANSTO began.
2015	The "TPS Inauguration Ceremony" was held.
2016	The "TPS Opening Ceremony" took place and the TPS phase-I beamlines opened to users worldwide.


▲ NSC Fiftieth Anniversary Science Trip (I) (2009).


▲ NSC Fiftieth Anniversary Science Trip (II) (2009).


▲ Annual Users' Meeting and Twentieth Anniversary of Operation (2013).


▲ Summer School of the Applications of the Synchrotron Light Source with Hands-on Training (2006).


▲ Lighting celebration for "World Year of Physics 2005" in Hsinchu (2005).


▲ Public art – A tranquil lucid heart.

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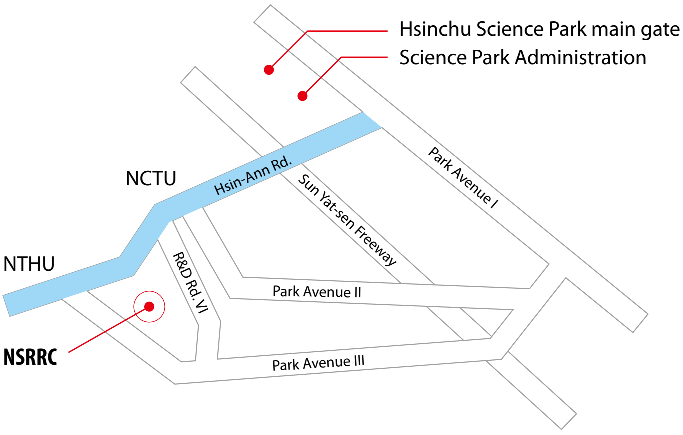

國家同步輻射研究中心
National Synchrotron Radiation Research Center

101 Hsin-Ann Road, Hsinchu Science Park, Hsinchu 30076, Taiwan, R.O.C.
Tel: +886-3-578-0281
Fax: +886-3-578-9816
http://www.nsrrc.org.tw