UVSOR

ULTRAVIOLET SYNCHROTRON ORBITAL RADIATION

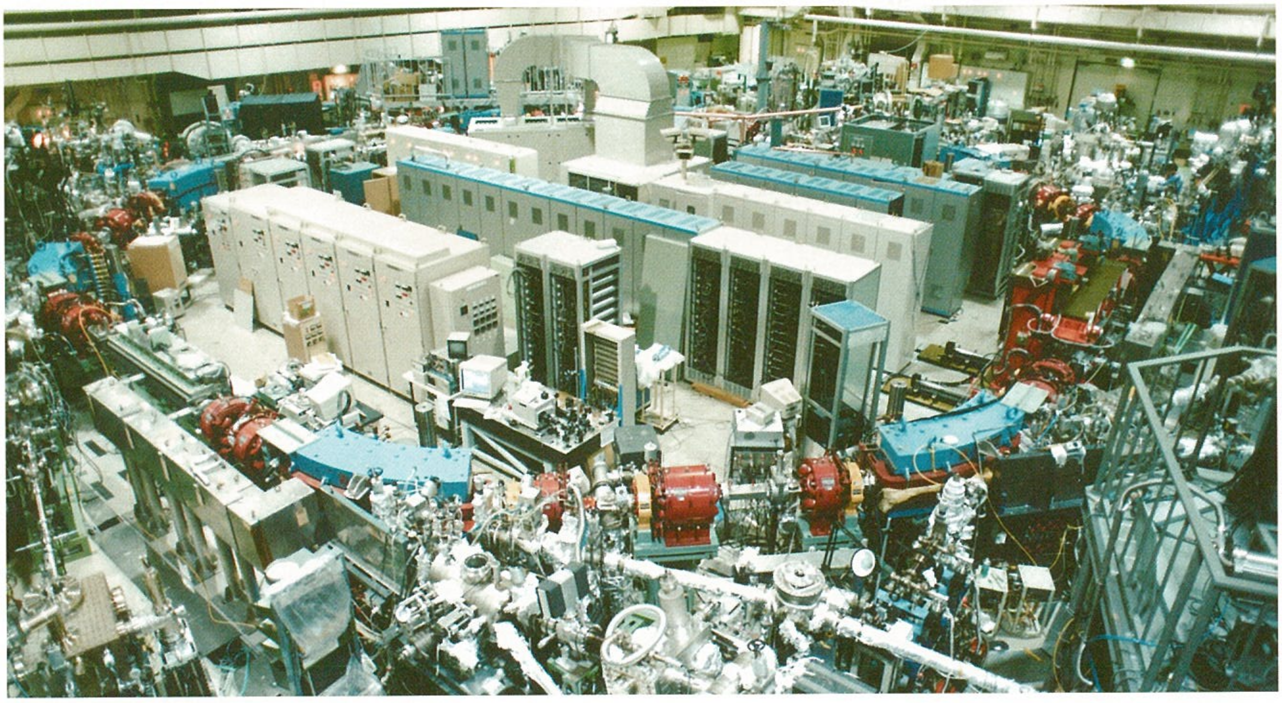
UVSOR FACILITY

INSTITUTE FOR MOLECULAR SCIENCE

岡崎国立共同研究機構　分子科学研究所

極端紫外光実験施設

Outline of the Ultraviolet Synchrotron Orbital Radiation Facility

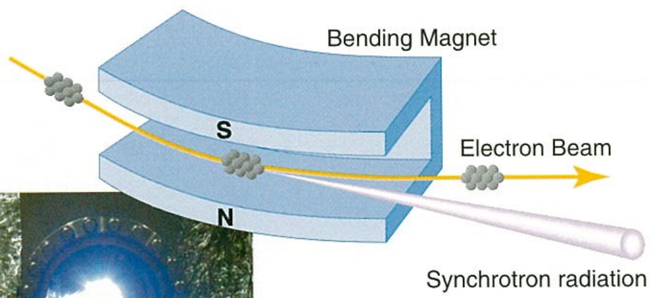


What is UVSOR?

The Institute for Molecular Science (IMS) is a national institute used by scientists who investigate new functional synthesis, reaction path ways, the utilization of photon energy and/or chemical energy etc., and basic researches on the structures and functions of molecules and molecular aggregates (clusters). The ultraviolet synchrotron orbital radiation facility (UVSOR) at the IMS is a synchrotron radiation light source research facility. Various investigations for molecular science are promoted at UVSOR with the use of synchrotron radiation.

What is synchrotron radiation?

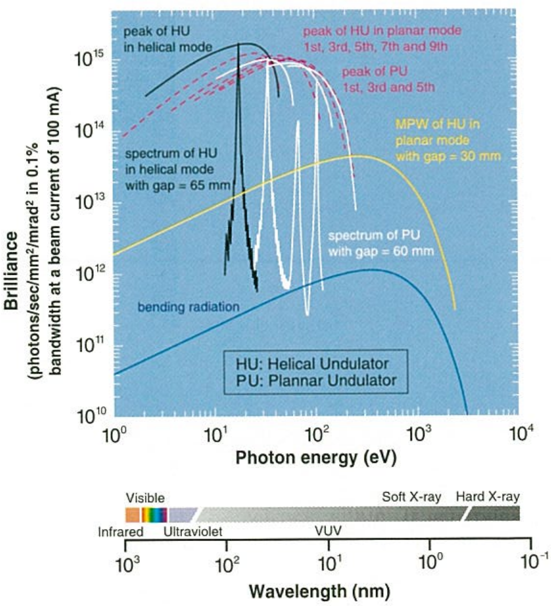
It is well-known that an electron emits electromagnetic radiation when the electron is accelerated. The radiation is also emitted when the electron traverses a magnetic field. If the velocity of the electron is almost the speed of light, the radiation emission pattern is concentrated markedly onto the forward direction, being tangential to the orbit of the electron. This is called "synchrotron radiation". Synchrotron radiation has a continuous spectrum ranging from infrared/visible light to ultraviolet/X-ray wavelengths. And synchrotron radiation also has many excellent properties such as being tightly collimated, highly polarized, sharply pulsed, and partly coherent. Various spectra of the radiation from the sources available at UVSOR are shown in the right figure.



Schematic view of synchrotron radiation

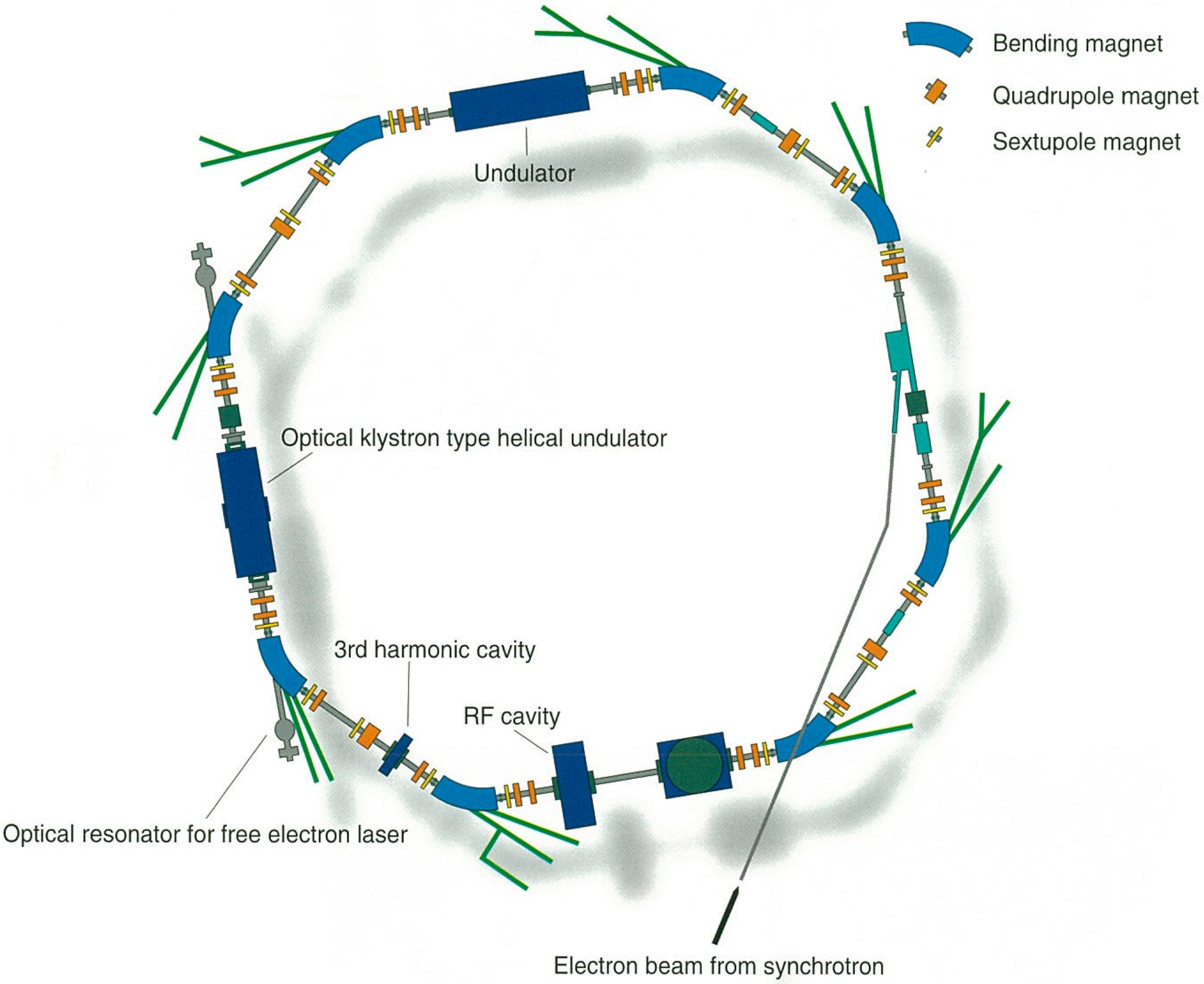
Photograph of synchrotron radiation in the visible region

The Synchrotron Radiation Spectrum of UVSOR



750 MeV Storage Ring

The UVSOR facility is composed of three accelerators, that is, a 15 MeV linear accelerator for electron injection, a booster electron synchrotron (about 8.5 m diameter) for accelerating the electron beam up to 600 MeV, and a 750 MeV storage ring for producing synchrotron radiation.

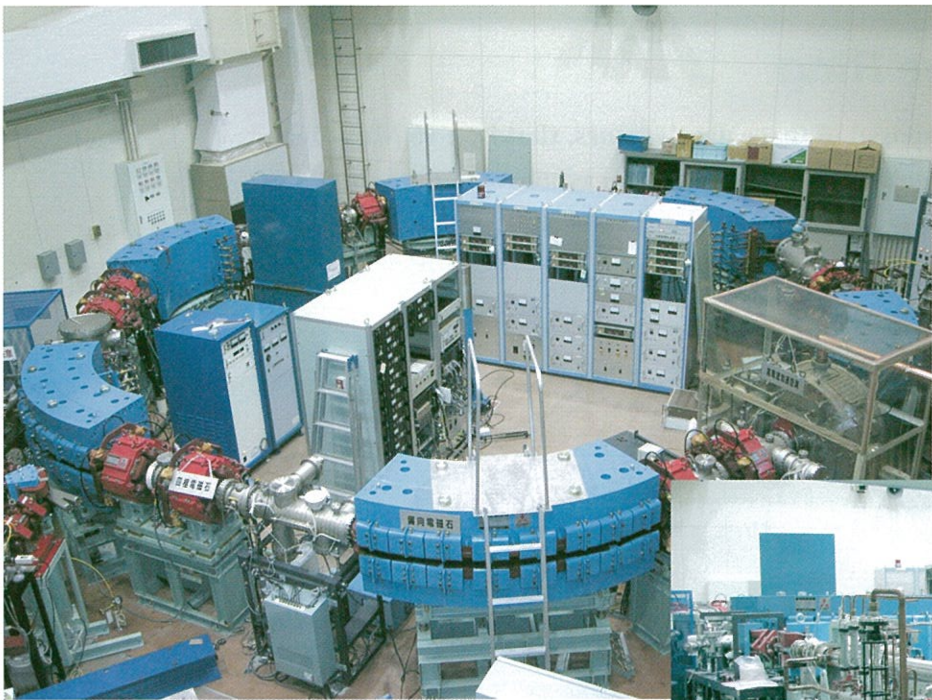


UVSOR Storage Ring

The storage ring has a quasi-octagonal shape with the combination of 8 bending magnets and 8 straight sections. In straight sections, undulators which are used for producing higher brightness synchrotron radiation and a RF cavity which is used for compensating energy loss through emitting synchrotron radiation are installed. There are 2 branch beamlines at each bending magnet section at UVSOR.

General parameters of the storage ring

Circumference	53.2 m
Energy	750 MeV (600 MeV at injection)
Number of bunches	Multi-bunch mode: 16
	Single bunch mode: 1
Initial stored current	Multi-bunch mode: 200 mA (max. 500 mA)
	Single bunch mode: 60~70 mA
Beam lifetime	Multi-bunch mode: 8 h (at 200 mA)
	Single bunch mode: 1 h (at 50 mA)
Beam sizes	0.39 mm (horizontal)/0.27 mm (vertical)
Pulsed light period	Multi-bunch mode: 11 ns
	Single bunch mode: 176 ns
Pulsed light width	~1ns with a harmonic cavity system (min. 20 ps)
Vacuum pressure	~1×10^{-10} Torr

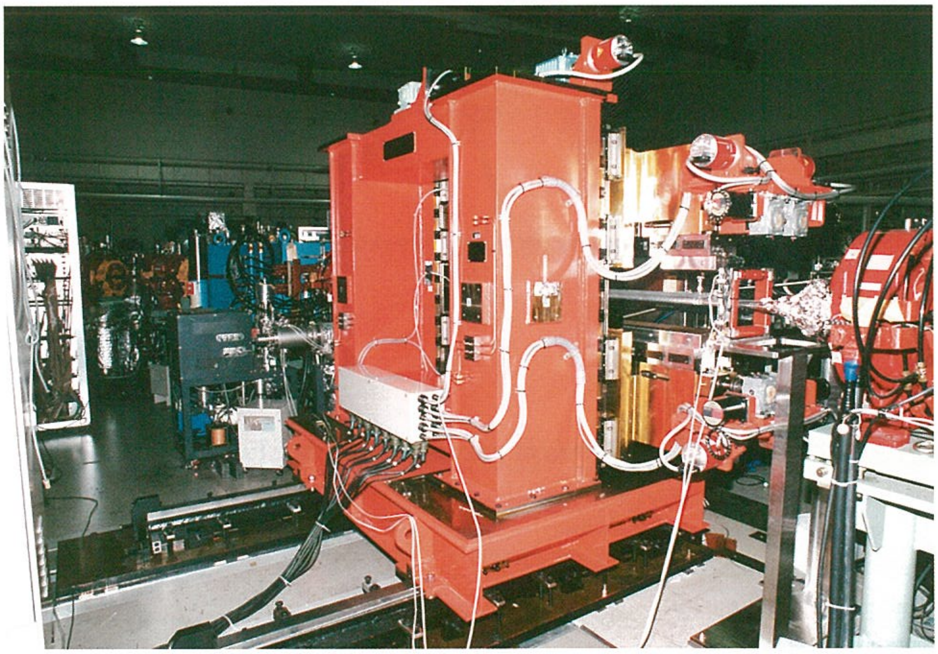


600MeV Electron Synchrotron

Electron Gun & Linac

Injectors

The injection system for the UVSOR storage ring comprises a linac and a booster synchrotron. The linac generates electrons with an electron gun and accelerates them to an energy of 15 MeV. The accelerated electron beam is injected to the booster synchrotron which raises the energy to 600 MeV. At this energy the electron beam is extracted from the booster synchrotron and transferred to the storage ring. The energy of stored electron beam in the storage ring is then raised to an operation energy of 750 MeV.



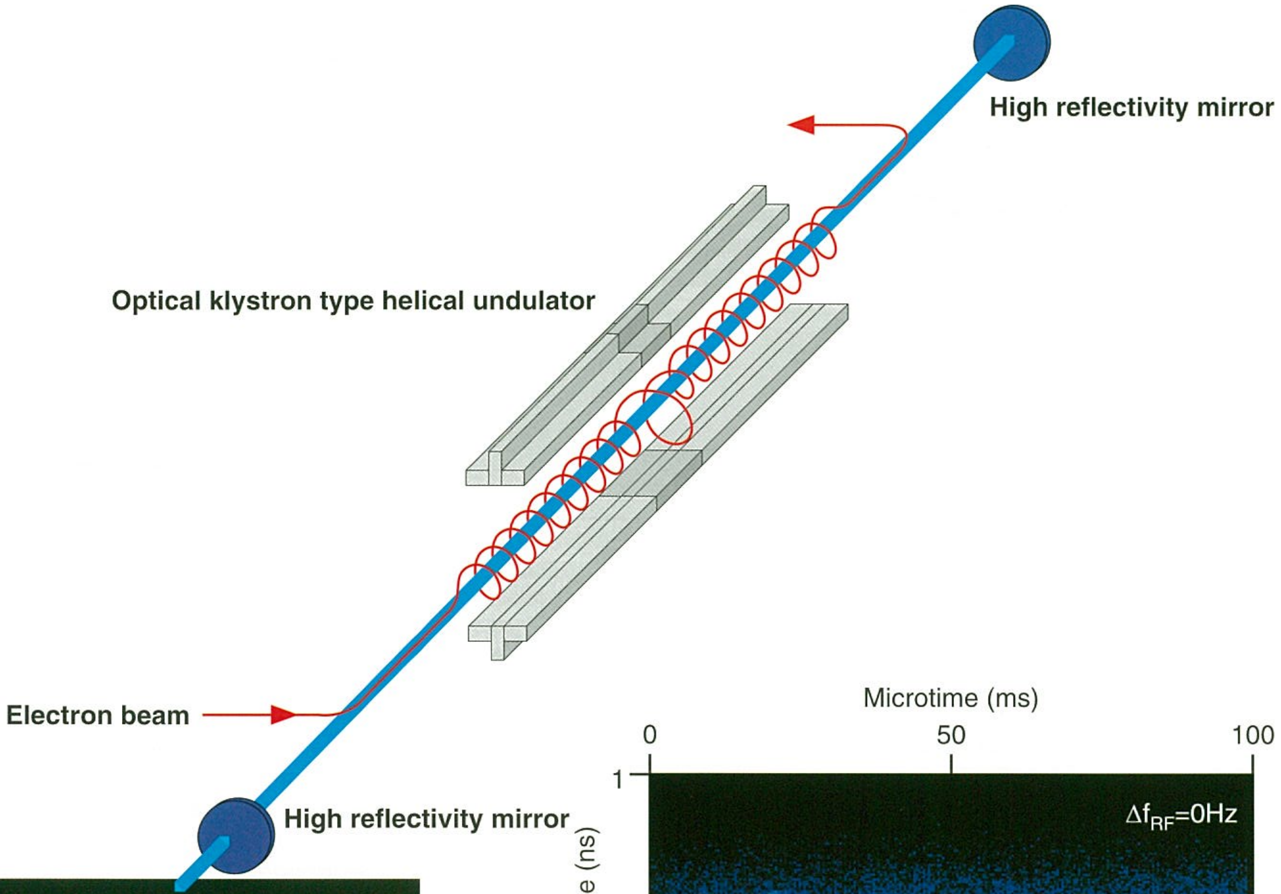
Helical Undulator

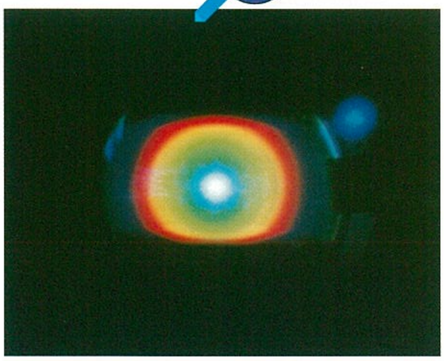
Undulator

An undulator is a device having periodic magnetic structures, which generate beams of radiation with higher brightness than the bending magnets. One of the two undulators installed in the storage ring of UVSOR has helical fields which produce circularly polarized radiation. This device is called "helical undulator" due to the movement of electrons within. It generates completely circularly polarized radiation ranging from 5 to 43 eV.

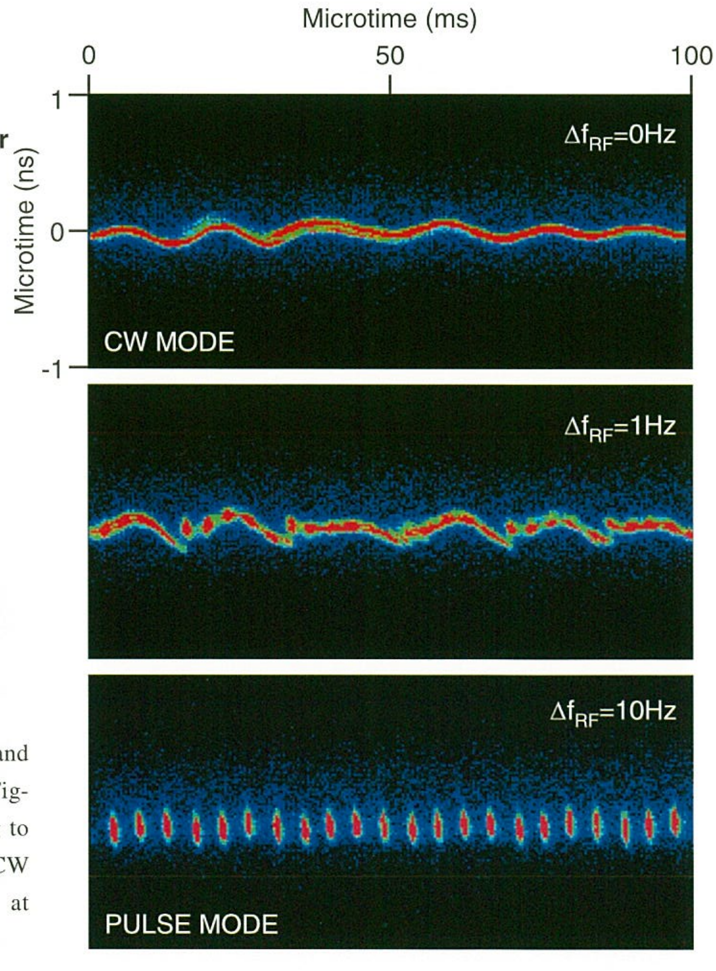
Free Electron Laser

The free electron laser (FEL) system is composed of an undulator and an optical resonator which consists of two mirrors facing each other at both ends of the undulator. Owing to the interaction of the high energy electron beam in the undulator field and the radiation in the optical resonator, laser action with positive gain takes place. At UVSOR, the shortest wavelength of FELs all over the world was successfully achieved by utilizing a helical optical klystron in 1997. Since 2000 the FEL has been used for users' researches.





FEL lasing in the visible region



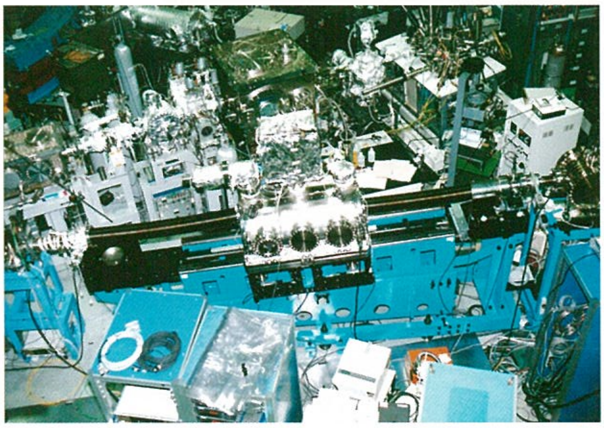
An accurate synchronization between an optical pulse and an electron beam is required for the stable FEL lasing. Figures show variation of temporal structure of FEL owing to only a small detuning. In users' experiments, the stable CW mode is kept using a feedback system developed at UVSOR.

Experiments using Synchrotron Radiation at UVSOR

In order to perform experiments using synchrotron radiation, a pre-focusing mirror system for introducing the radiation to an experimental setup, a monochromator for selecting a certain photon energy, and an instrument for data taking are required. A total combination of these elements is called "beamline" and every beamline is numbered. At UVSOR, priority has been given to the research fields related to the following subjects; 1) spectroscopic investigations (absorption, reflectivity and luminescence), 2) photoelectron spectroscopy, 3) photochemistry, 4) basic processes of chemical reaction, 5) photochemistry of solid state and surfaces, and 6) syntheses of new materials by photoexcitation. The preparation of beamline systems for such research fields results in growing scientific activities at UVSOR. The list of all available beamlines at UVSOR and their related experimental apparatuses are summarized below.

Beamlines of UVSOR

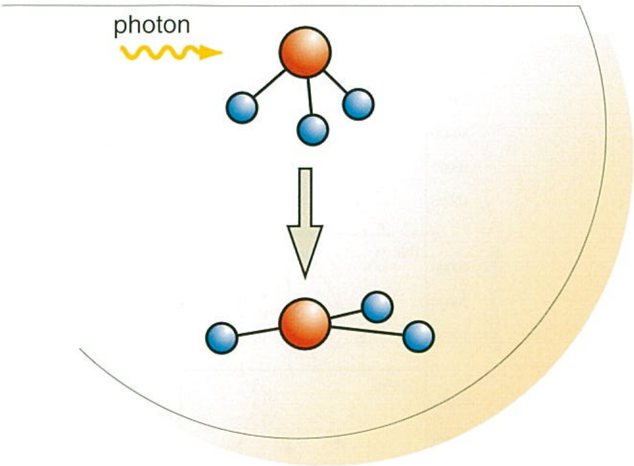
Beamline	Monochromator	Wavelength Region	Experiment
BL1A	Double Crystal	2.1 - 0.3 nm	Solid state (photoemission)
BL1B	1m Seya-Namioka	650 - 30 nm	Solid state (absorption)
BL2A	1m Seya-Namioka	400 - 30 nm	Bioscience (irradiation)
BL2B1	2m Grasshopper	60 -1.5 nm	Solid & Surface (photoemission, absorption)
BL2B2	18m Spherical Grating	60 - 6 nm	Gas(photoemission, photodissociation)
BL3A1	None (Filter, Mirror)	50 -15 nm	Solid & Irradiation (photodissociation)
BL3A2	2.2 m Constant Deviation Grazing Incidence	100- 10 nm	Gas & Solid (photoionization & photodissociation)
BL3B	3m Normal Incidence	400- 30 nm	Gas (photoemission)
BL4A1	Multi-Layered-Mirror Monochromator	23- 13 nm Mo/Si MLMs	Irradiation
BL4A2	—		Lithography
BL4B	Varied-line Spacing Plane GratingMonochromator	1.5- 14 nm	Gas(photoemission,photodissociation)& Solid (photoemission)
BL5A	SGM-TRAIN	250 - 5 nm	Solid (absorption) Free Electron Laser
BL5B	Plane Grating	200 - 2 nm	Calibration, Gas & Solid (photodissociation & absorption)
BL6A1	Martin-Puplett FT-IR Michelson FT-IR	3000 - 30 mm	Solid (absorption)
BL6A2	Plane Grating	650 - 8 nm	Solid (photoemission)
BL6B	None		Irradiation
BL7A	Double-crystal	1.5 - 0.8 nm	Solid (absorption)
BL7B	3m Normal Incidence	1000 - 50 nm	Solid (absorption)
BL8A	None (Filter)		Irradiation & Users' Instruments
BL8B1	15 m Constant Deviation Grazing Incidence	40 - 2 nm	Gas & Solid (absorption)
BL8B2	Plane Grating	650 - 8 nm	Solid (photoemission)



Spectrometer "SGM-TRAIN"

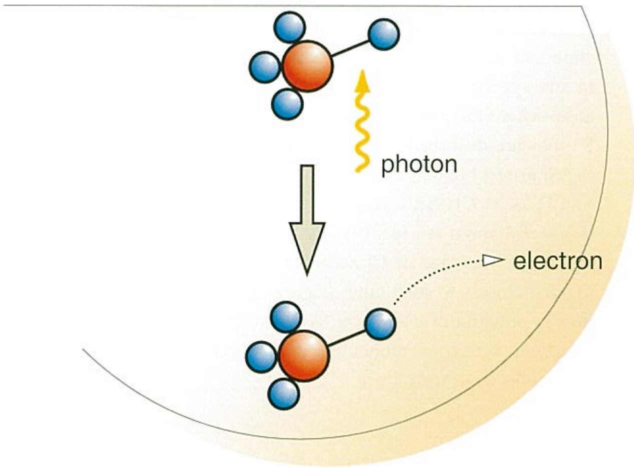
① Absorption spectroscopy

Observation of absorption spectra of photons on materials (molecules).



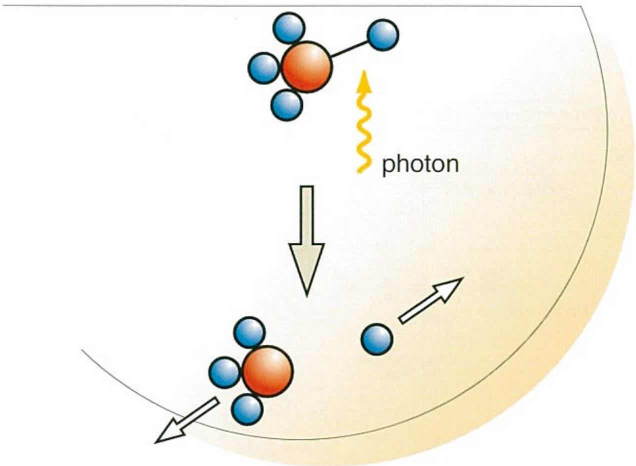
② Photoelectron spectroscopy

Observation of electrons' emission from materials (molecules) irradiated with synchrotron radiation photons.



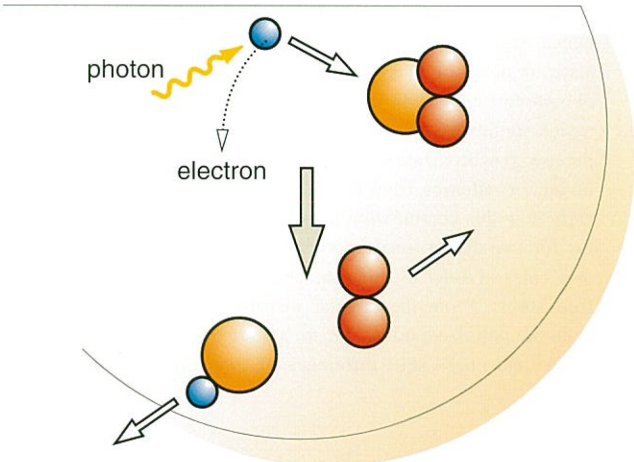
③ Photochemistry

Studies of chemical reactions using synchrotron radiation photons.



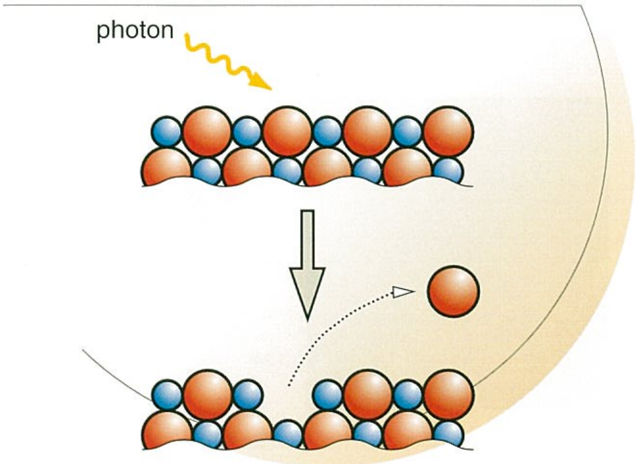
④ Basic processes of chemical reaction

Studies on behavior of ions and radicals using synchrotron radiation photons.



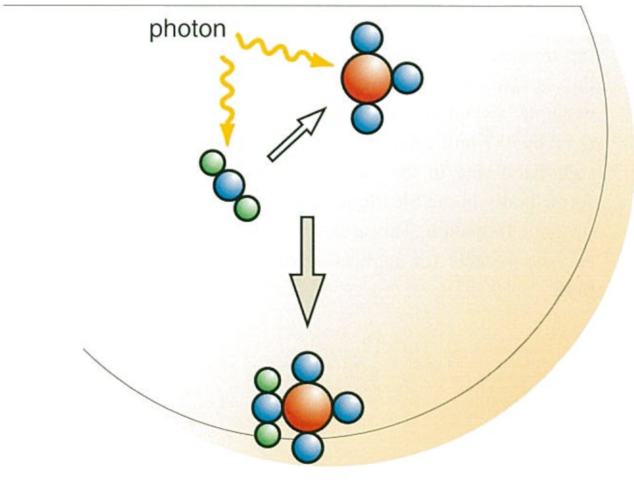
⑤ Photochemistry of solidstate (surface)

Studies of the dynamical behavior of solidstate(surfaces) irradiated with synchrotron radiation photons.



⑥ New functional synthesis by photoexcitation

Synthesis of a new molecule using synchrotron radiation photons.

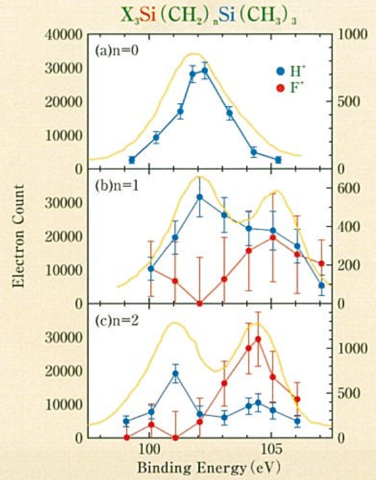


Recent Research Activities at UVSOR

Examples of recent research activites are presented here.

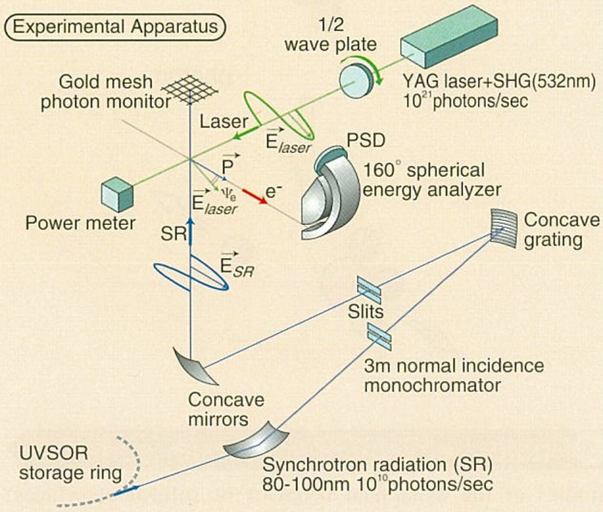
Investigation of Ion Desorption Caused by Core-Level Excitation – Application to Optical Knife –

Monochromatized synchrotron radiation can excite the core electrons of an atom in a specific chemical environment selectively, discriminating the core electrons from those of atoms in different chemical environments. This site-specific excitation often results in site-specific fragmentation, which occurs selectively around the atom where the photoexcitation has taken place. In fact, the H^+ and F^+ ions are desorbed by the photoionizations of the 2p electrons of the Si atoms bonded to the methyl groups and the fluorine atoms in $Si(CH_3)_3CH_2CH_2SiF_3$, respectively (figure c). However, one should be careful about the fact that the site-specific fragmentation is negligible for the case of $Cl_3SiSi(CH_3)_3$ in which the two Si sites are located closely to each other (figure a). The site-specific fragmentation is potentially useful for synthesizing materials through selective bond breaking: monochromatized synchrotron radiation could be used as an optical knife.



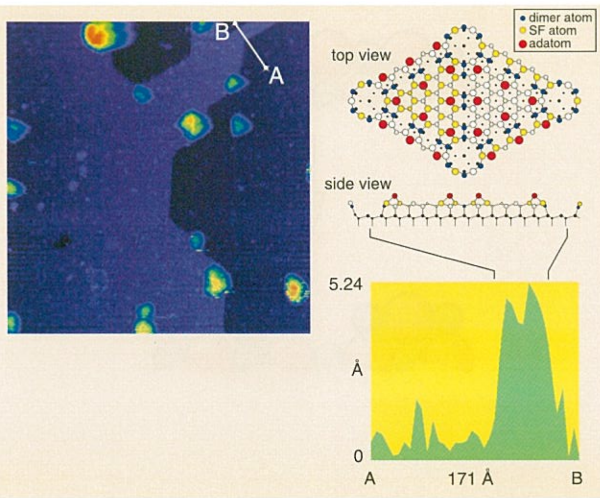
Experiments combining laser with synchrotron radiation

Combining laser with synchrotron radiation has attracted widespread attention of molecular scientists, in connection with possibilities for conducting various types of pump-probe or double resonance experiments on spectroscopy and dynamics of rovibronic states in detail by making the most use of different features of the two photon sources. In UVSOR, laser-synchrotron radiation combination studies have been realized for many molecular systems by a precise synchronization of a mode-locked Ti:sapphire laser with undulator radiation from BL3A2. The illustration shows schematically how this combination technique is combined with an apparatus for two-dimensional photoelectron spectroscopy of atoms and molecules in order to study the photoionization dynamics of polarized atoms. From the angular distribution of the photoelectrons from the polarized atoms, we are able to gain insight into the magnitude and phase shift difference of transition dipole matrix elements.



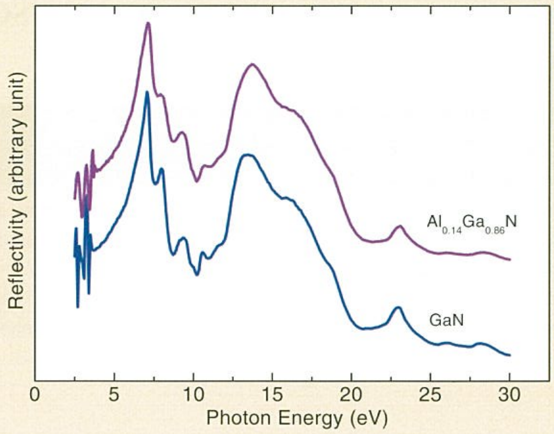
Silicon Nanostructure Self-Formation by illumination of Synchrotron Radiation

Si wafers covered with oxide were irradiated by Synchrotron Radiation (SR) at ~700 ℃. The surface was observed by scanning tunneling microscope (STM) after several hours illumination of SR. On the surface, we found unique self-formed Si nanostructures, for example, a single monolayer thick stripe of which width was quantized by 7x7 unit cells of surface reconstruction, as shown in upper right-hand side in the figure. Because these nanostructures were formed only in the SR illuminated area, any position can be chosen for their formation. This area selective formation of nanostructures may be suitable for application of biochip and biosensor fabrication.



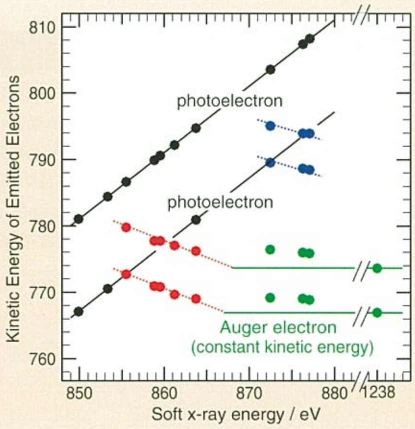
Reflection spectra of nitride ternary alloys

The blue LED has become a popular LED today, along with the red, yellow and green ones. This is due to the drastic development of the III-V nitrides thin films growth technique, because the III-V nitrides (mainly GaN) are the key material of blue LED. Furthermore, III-V nitride ternary (or more) alloys are the probables of the violet and ultraviolet LEDs. Since the UVSOR is a wide wavelength range lightsource, we can investigate the basic optical properties of these III-V nitride alloys using reflectance (see figure), emission and excitiation spectra at visible (red to violet), ultraviolet and vacuum ultraviolet regions.



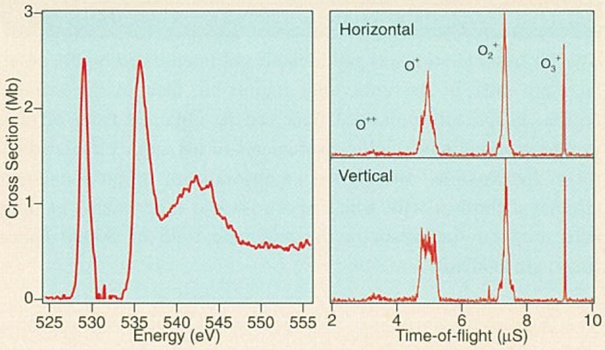
Resonant Photoelectron spectra of Nickel Complexes

When materials absorb a soft x-ray photon, electrons are emitted with various kinetic energies.Emitted electron with kinetic energy linearly increased to the incident x-ray is called photoelectron. Electron, which has the constant kinetic energy regardless of the x-ray energy is known as Auger electron. We have discovered a new kind of emitted electrons in nickel complex with cyano ligands (dotted line in the figure); they slow down as x-ray energy increases. Detail behavior of these electrons, as well as photoelectrons and Auger electrons, shed light onto the bonding and electronic structure of the nickel complexes.



Study of electronic excited states of ozone

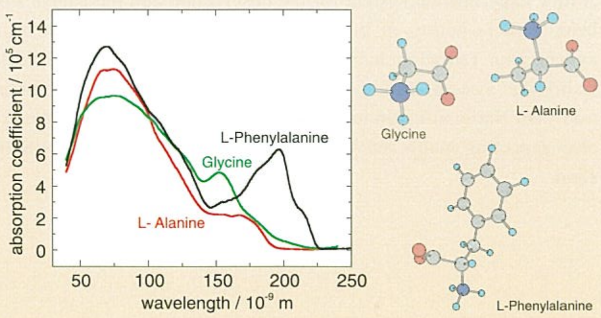
Ozone is one of the most important molecules in chemistry since ozone in the stratosphere absorbs UV light emitted from the sun and protects humanity from the exposure by the UV light. In view of this ozone effect, many experimental and theoretical exertions have been devoted to the spectroscopic studies of ozone. In order to explore the electronic states of ozone, we have constructed an ozone supply apparatus on the beamline BL8B1 at UVSOR facility. The photoabsorption spectra (left figure) and time-of-flight spectra of ion photofragments (right figure) have been successfully measured for the first time in the soft X-ray region 520-555 eV. These data are particularly useful for the determination of electronic states of ozone.



Absorption spectra of amino acids

Due to the fact that oxygen did not exist in the atmosphere of the earth before the onset of photosynthesis, vacuum ultraviolet radiation may have been a driving energy source of the molecular evolution prior to the orgin of life.

Vacuum ultraviolet absorption spectra of amino acids are being measured at UVSOR in an attempt to study the molecular evolution driven by the vacuum ultraviolet radiation.

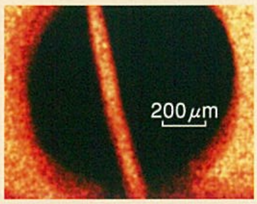


Equipments at UVSOR

There are a lot of unique equipments at UVSOR.
Some are shown in the following:

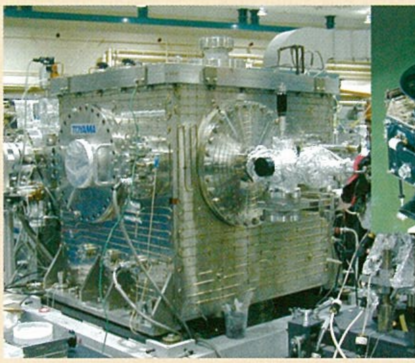
Photoelectron spectro-microscope with the combination of SR and Laser

A newly developed photoelectron spectro-microscope that can measure the specific small area of the sample has been installed at BL6A2. The femto-second laser system was also installed to conduct the combination experiment with SR and laser. Using this system, photoelectron micro-spectroscopic studies of various photo-induced phenomena can be conducted.



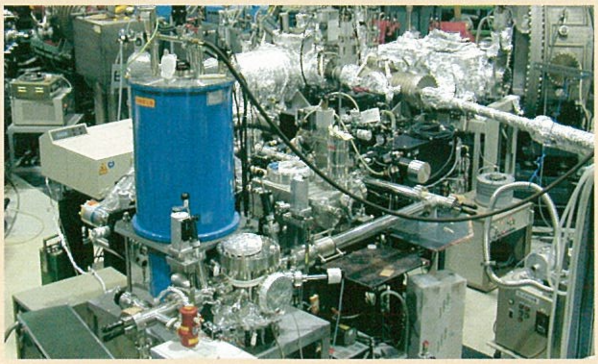
Calibration apparatus of optical elements

Synchrotron radiation contains soft X-ray which is absorbed by the air and is accessible in wide energy range. Thus synchrotron radiation can be used as "standard light" for the calibration of optical elements. Beamline BL5B has a purposed-build UHV calibration apparatus for optical elements. Calibration experiments of various soft X-ray optical elements, such as mirrors of soft X-ray telescope for satellites, are performed.



Infrared magnetic circular dichroism measurement apparatus

Synchrotron radiation has good features of intense and highly polarized not only in the ultraviolet region but also in the infrared region. Elliptically polarized light can be obtained from off-axis synchrotron radiation and measurements of magnetic circular dichroism are possible. BL6A1 has an apparatus of infrared magnetic circular dichroism with which spectroscopic experiments of magnetic circular dichroism in the magnetic field of 80000 Gauss (max) are available.



Irradiation Apparatus for Biology

A new experimental system for the observation and the analysis of behavioral responses of micro-organisms to ultraviolet light from synchrotron radiation has been constructed at beamline BL2A. Using this system, biology experiments have started in collaboration with National Institute for Basic Biology and the IMS. We are also expecting many active bioscientists to come to use UVSOR soon.

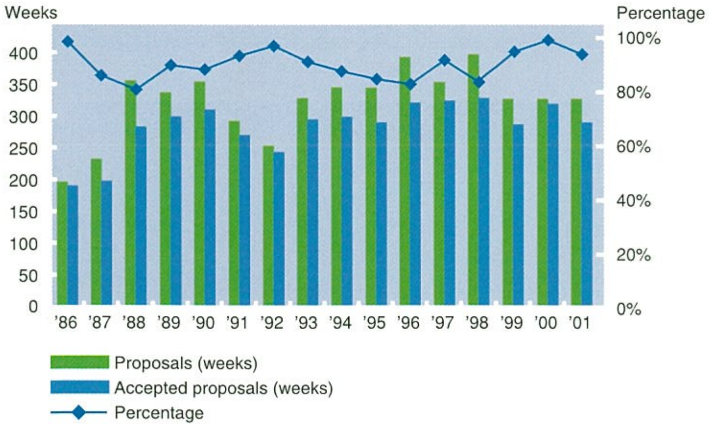
Collaborations

The synchrotron radiation of UVSOR is available for researchers within the Institute for Molecular Science (IMS) and from other universities and institutes. Various investigations related to molecular science are performed using UVSOR by IMS researchers mainly belonging to the Department of Vacuum UV Photoscience. Biology experiments using synchrotron radiation of UVSOR are performed in the collaboration between National Institute for Basic Biology and IMS.

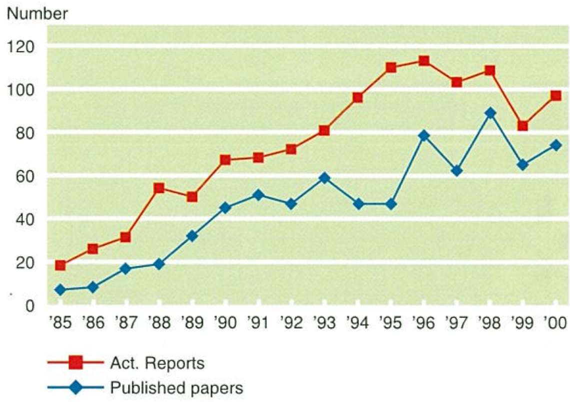
Many researchers outside IMS visit UVSOR to use synchrotron radiation. The number of visiting researchers is about 800 from 60 institutes per year. International collaboration is also active and the number of visiting foreign researchers is over 80 from 10 countries.

UVSOR calls for proposals twice a year and also accepts proposals from industries (charged).
All the work using UVSOR are reported in the UVSOR ACTIVITY REPORT and the number of refereed publication is more than 60 since 1996.

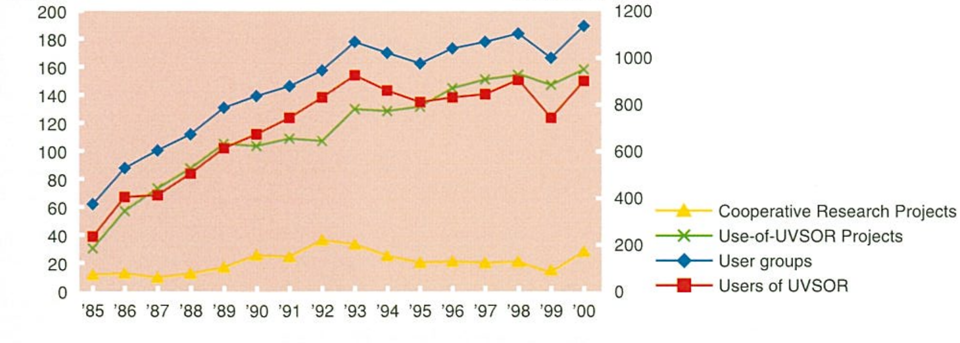
Number of accepted proposals

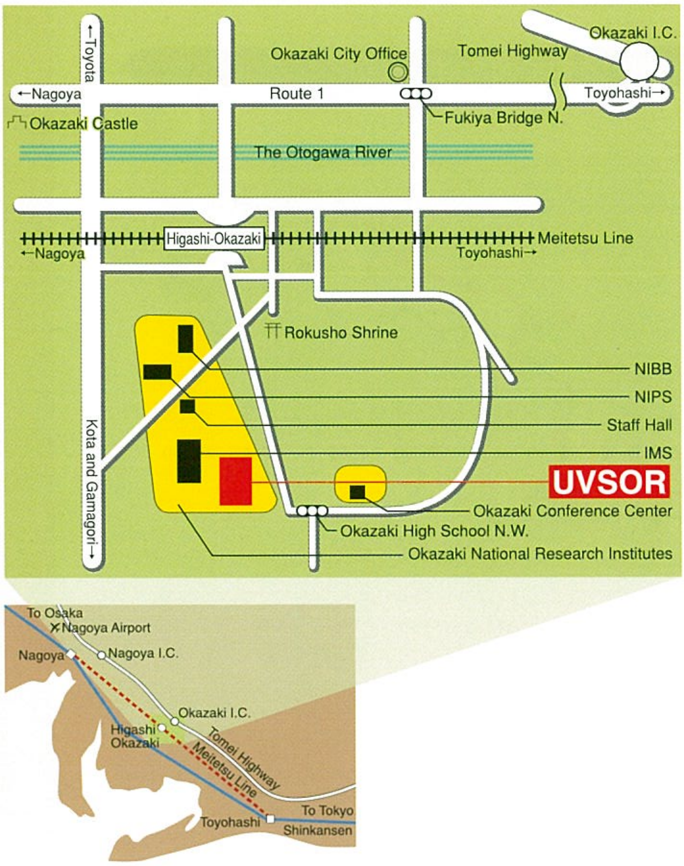


Number of published papers



UVSOR joint studies





Ultraviolet Synchrotron Orbital Radiation Facility

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