Future of SR

Tetsuya Ishikawa
RIKEN Harima Institute

18 October 2010 for Cheiron School

New Light Always Creates New Science & Technology

Plan

- This lecture, titled 'Future of SR', is designed to give you some background of SR history, then, discusses the possible future of SR facilities and sciences.
- Strategies for future may be different from person to person, or place to place, but important thing is to think about **YOUR** own future.
- Join us to make **NEW HISTORY OF SR** which is not the mere extrapolation from the present!

Brief Introduction of myself

- My name is Tetsuya Ishikawa. I am the Director of RIKEN SPring-8 Center and the Project Leader of X-ray Free Electron Laser.
- My research field is X-Ray Optics including those for coherent x-rays.
- I have been working around the SR facilities since 1982 when the Photon Factory started operation.
- I had been the Optics Group Leader/Beamline Division Director till 2006 when Dr. Shunji Goto took over the position.

You are learning a lot in this school ...

Thank you for joining us in this Cheiron School 2010. Now, you are attending the lecture titled "**Future of SR**".

You are learning a lot about synchrotron radiation and its applications in the preceding and following lectures. It is not surprising that you may feel the science and technologies related to the synchrotron radiation are too widely diverse to be an expertise in everything.

Don't be afraid, because no one can cover everything!

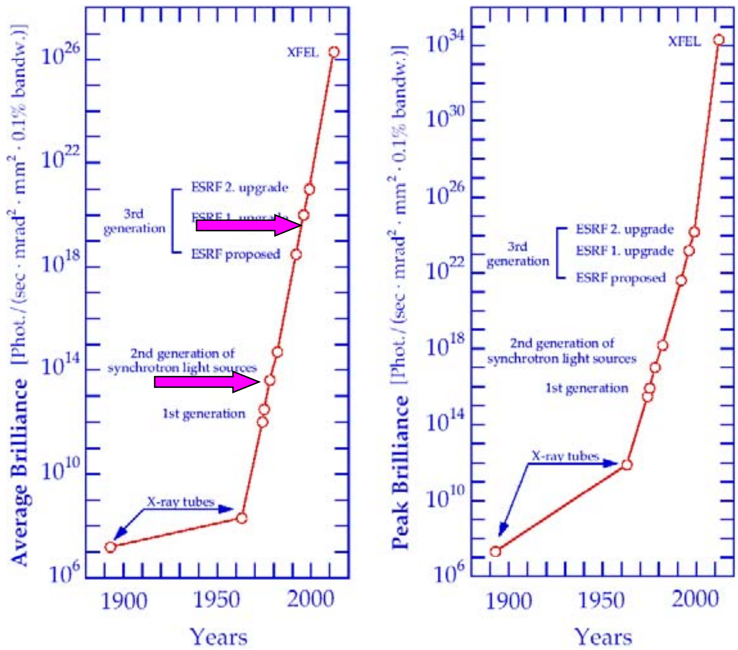
You can be the world's top scientist in a certain field.

You have to know where you are...

All lectures given in this school are the maps of science/technology fields that have been already explored by other scientists. All of you, who are young with full potential, may want to construct new roads in the fields. So focus yourselves where you are on the map to start with.

New possibilities really lie in what has not been directed in the lectures: It is you to explore the new roads and to make the new SR history!

History can tell you something…



SR history has been a pursuit of Brilliance.

Short History of Synchrotron Radiation

1945 First (indirect) observation of SR; J. Blewett, G.E. 100 MeV betatron
1947 1st visual observation; G.E. 70 MeV synchrotron

ZEROth GENERATION SOURCES
1950's-60's: ELECTRON SYNCHROTRONS (cyclic accelerators)

FIRST GENERATION SOURCES (storage rings)
1970's: *e+/e- COLLIDERS (Mostly Parasitic on High Energy Physics programs)*

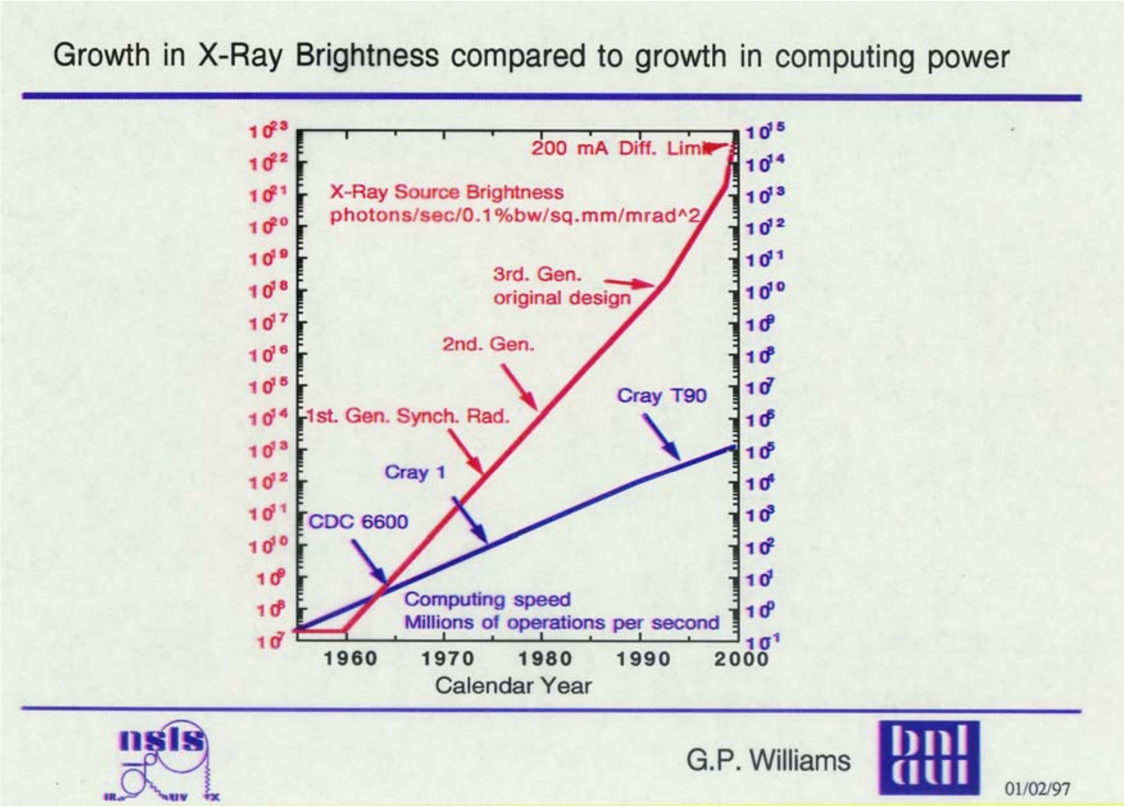
SECOND GENERATION SOURCES
1980's: *NEW RINGS* and *FULLY DEDICATED USE OF e+/e- COLLIDERS,*
USE OF WIGGLERS & UNDULATORS

THIRD GENERATION SOURCES
1990's: *LOW EMITTANCE RINGS WITH MANY STRAIGHT SECTIONS*

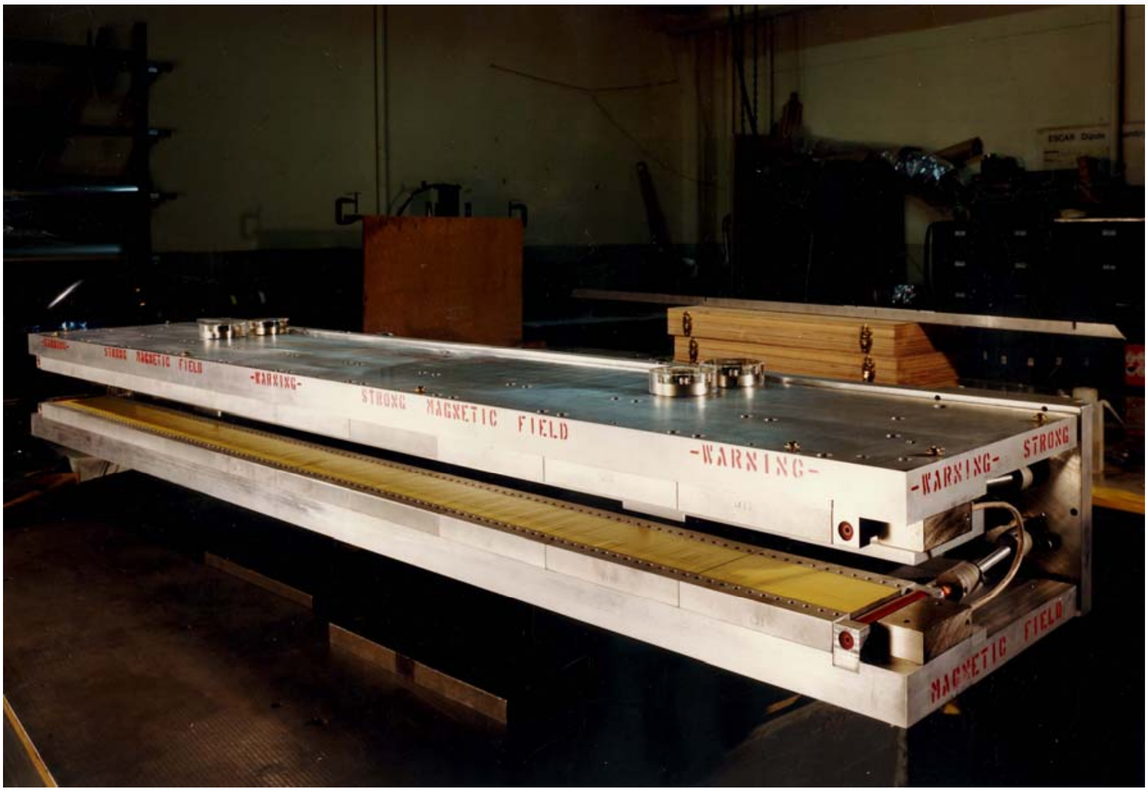
FOURTH GENERATION SOURCES
2000's: LINAC-BASED SOURCES
- Free-electron laser (FEL)
- Energy Recovery Linac (ERL)

DIFFRACTION-LIMITED RINGS; ULTRA-SHORT BUNCHES; NEW IDEAS

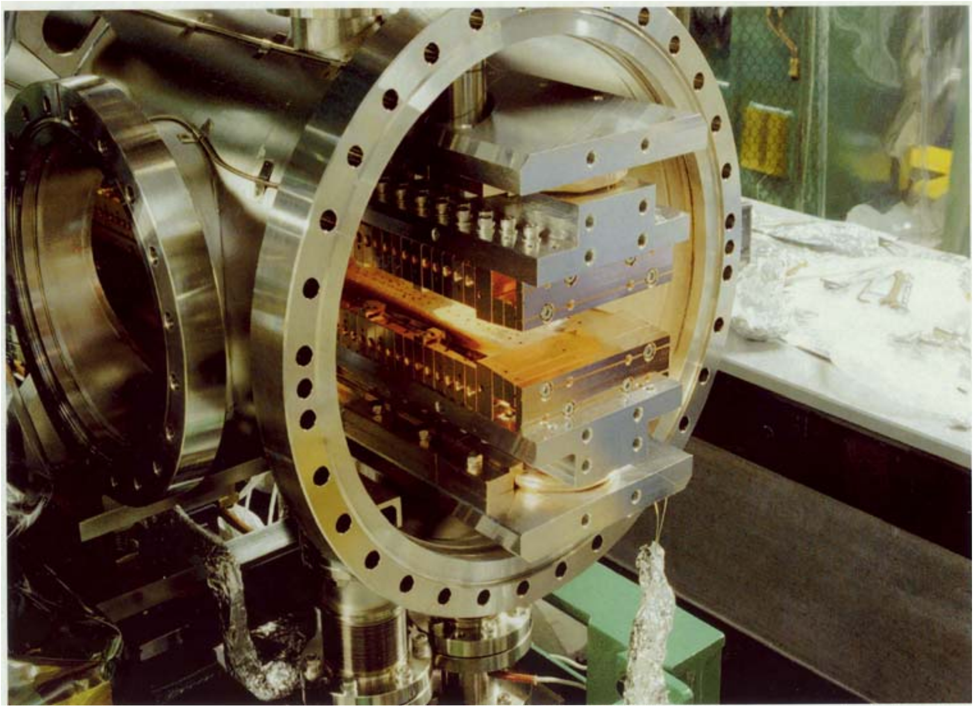
SR brightness has grown faster than the computing Power



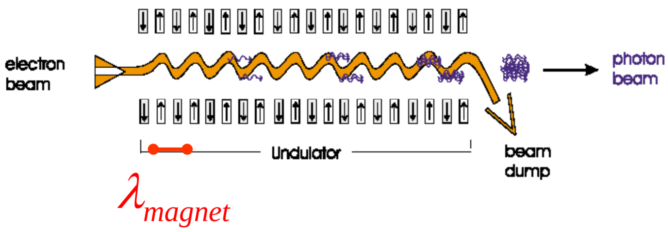
LBL/SSRL 30 Period Permanent Magnet Undulator -1980



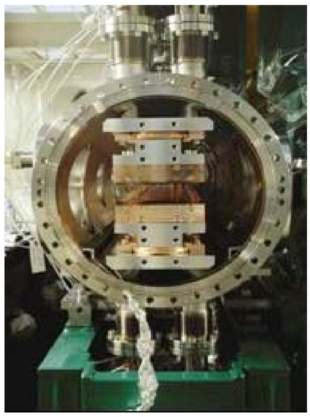
In-Vacuum Permanent Magnet Undulator in SPring-8



Short-period in-vacuum undulator



Dr. Kitamura



$$\lambda_{photon} = \frac{\lambda_{magnet}}{2\gamma^2}\left(1+\frac{K^2}{2}\right)$$

$$\gamma = 2{,}000 \times E(GeV)$$

For λ_{photon} = 0.1 nm: (K=2)

λ_{magnet}= 30 mm, E = 11 GeV

λ_{magnet}= 18 mm, E = 8 GeV

cf. λ_{magnet} = 100 um, E = 600 MeV !!

In-vacuum undulator:

- Short-period undulator requires higher magnetic field for deflecting electrons. Magnets are located "in vacuum" for generating higher field with smaller gap (~ 3 mm).
- Variable gap undulator

In-vacuum undulators

- In-vacuum undulator technology was a turning point of the SR history.
- This is the reason why SPring-8 had been the world-largest synchrotron radiation facility for ~10 years.
- With the in-vacuum undulator technology, lower energy storage rings can emit x-rays from undulators.

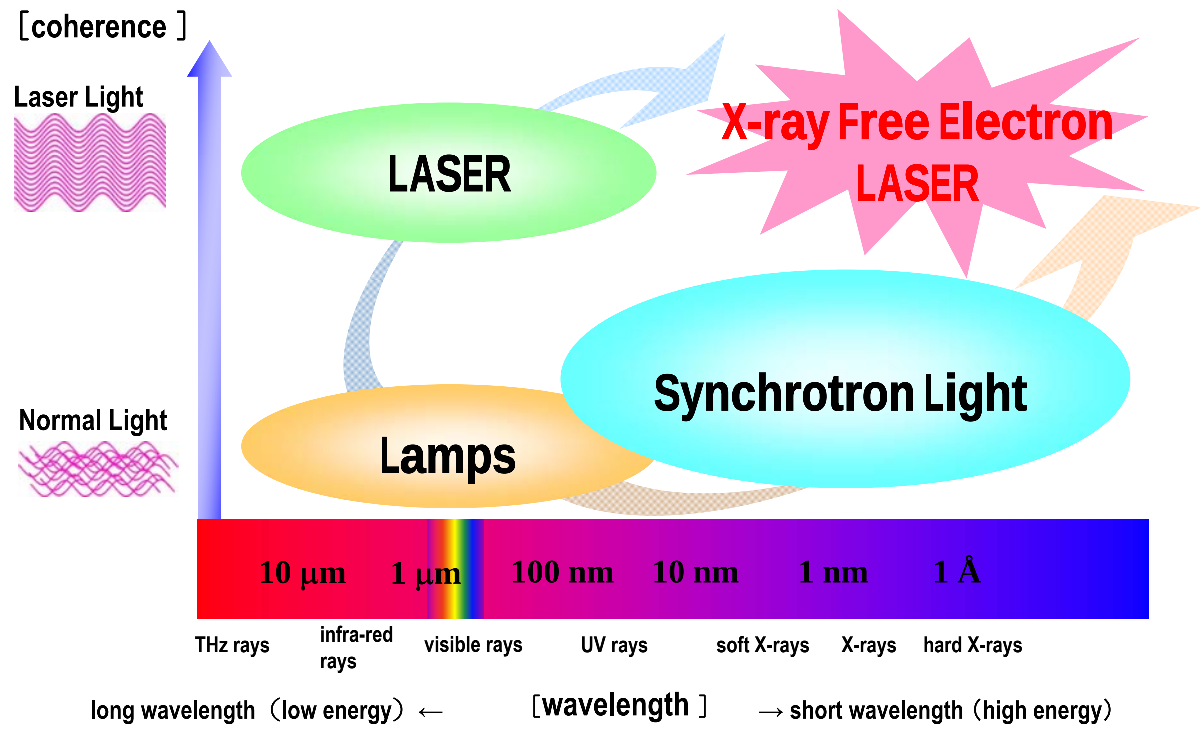
Down-Sized SR Facilities

It's our tradition to make everything compact.

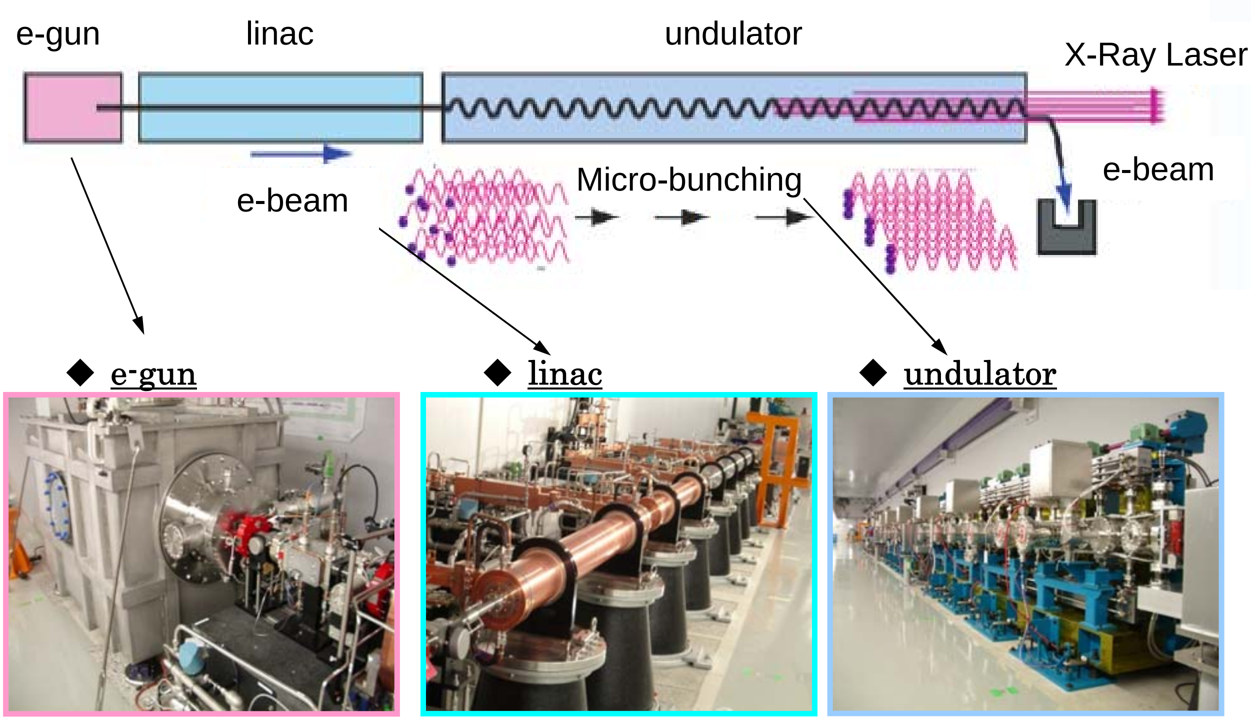
Bonsai

So is XFEL…

"X-ray Free Electron Laser, XFEL"
coherent light to explore nano-world



Linac-Based Free Electron Laser
Self-Amplified Spontaneous Emission (SASE)

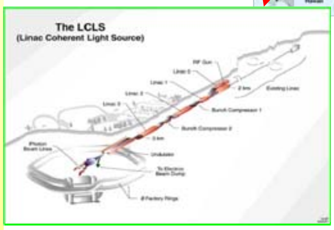


Precedent XFEL Projects in the U.S. and EU

【US】 SLAC : Stanford Linear Accelerator Center

Liniac Coherent Light Source : LCLS

- Use Existing 2 mile Liniac
- Size: 2 km long
- Shortest Operating Wavelength: 0.15 nm
- To Start Operation in 2009
- RF gun/Normal Conducting Liniac/Out-of-Vacuum Undulator
- 3rd Priority in DOE's Future Facility Plan

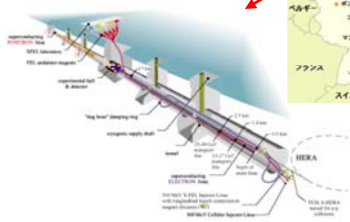


LCLS

【EU】 DESY : Deutsches Elektronen-Synchrotron

European X-Ray Free-Electron Laser

- Collaboration among 12 EU Countries + China
- Size: 3.4 km long
- Shortest Operating Wavelength: 0.085 nm
- To Start Operation in 2013
- RF gun/Superconducting Liniac/Out-of-Vacuum Undulator



European XFEL

Japan's XFEL:
SPring-8 Compact SASE Source (SCSS) Concept

Use of short-period undulator

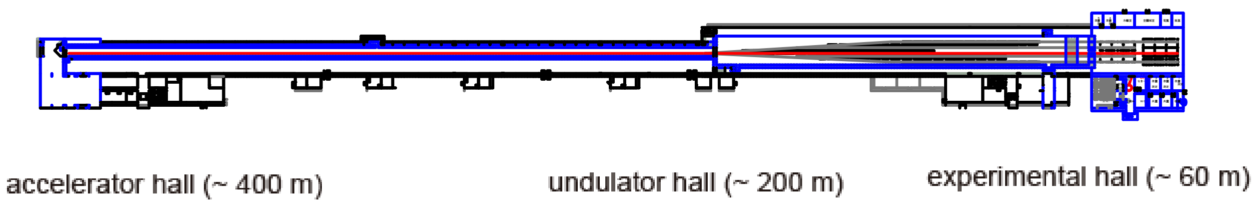
⇩

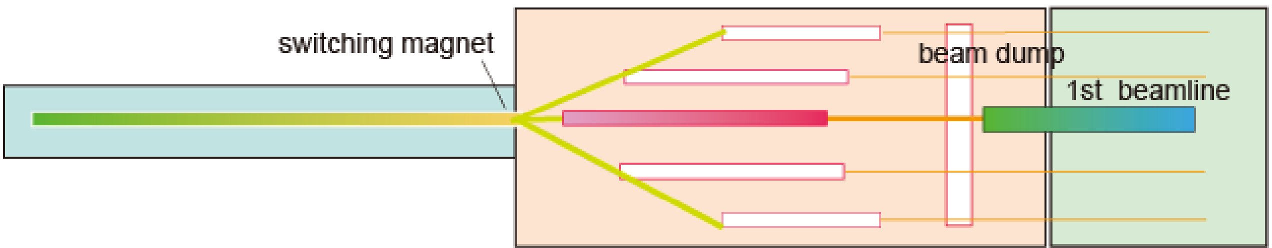
Suppression of acceleration energy

\+ Use of high-gradient linac

= Total length of 700 m

$$\lambda_{photon} = \frac{\lambda_{magnet}}{2\gamma^2}\left(1+\frac{K^2}{2}\right)$$





8 GeV X-Ray Free Electron Laser Facility at SPring-8

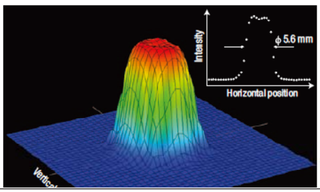
A compact free-electron laser for generating coherent radiation in the extreme ultraviolet region

A list of authors and their affiliations appears at the end of the paper

Published online: 27 July 2008; doi:10.1038/nphoton.2008.134

Single-pass free-electron lasers based on self-amplified spontaneous emission[1–4] are enabling the generation of laser light at ever shorter wavelengths, including extreme ultraviolet[5], soft X-rays and even hard X-rays[6–8]. A typical X-ray free-electron laser is a few kilometres in length and requires an electron-beam energy higher than 10 GeV (refs 6, 8). If such light sources are to become accessible to more researchers, a significant reduction in scale is desirable Here, we report observations of brilliant extreme-ultraviolet radiation from a 55-m-long compact self-amplified spontaneous-emission source, which combines short-period undulators with a high-quality electron source operating at a low acceleration energy of 250 MeV.
wavelengt
energy of
electron
degraded
dramatic
achievem
electron l

Synch
with wav



FREE-ELECTRON LASERS

A down-sized design

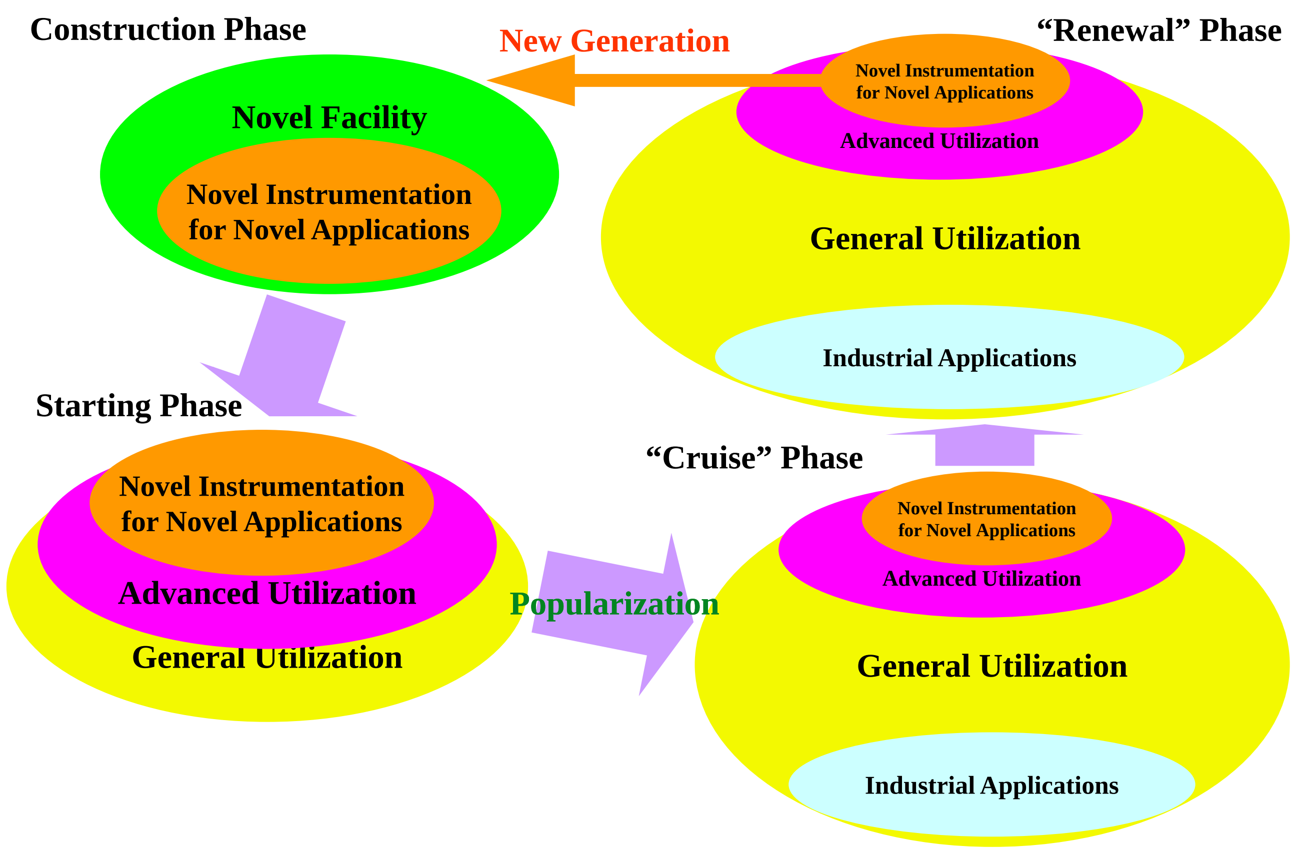
Necessity is the mother of invention. Lasing in the extreme UV from a prototype compact free-electron-laser design is reported, continuing the push towards X-ray wavelengths.

Brian McNeil
is in the Department of Physics, University of Strathclyde, Glasgow G4 0NG, UK.
e-mail: b.w.j.mcneil@strath.ac.uk

High-gain free-electron lasers (FELs) to observe phenomena at these scales also offers the enticing prospect of being able to control them. Recent progress towards these dreams has been made on a prototype of a Japanese X-ray FEL (XFEL) — the SPring-8 commissioning pencilled in for late 2013. Although the existing linear accelerator (Linac) at SLAC provided the LCLS team with a flying start, they have had the tricky task of adapting a system built at the end of the 1960s. Meanwhile,

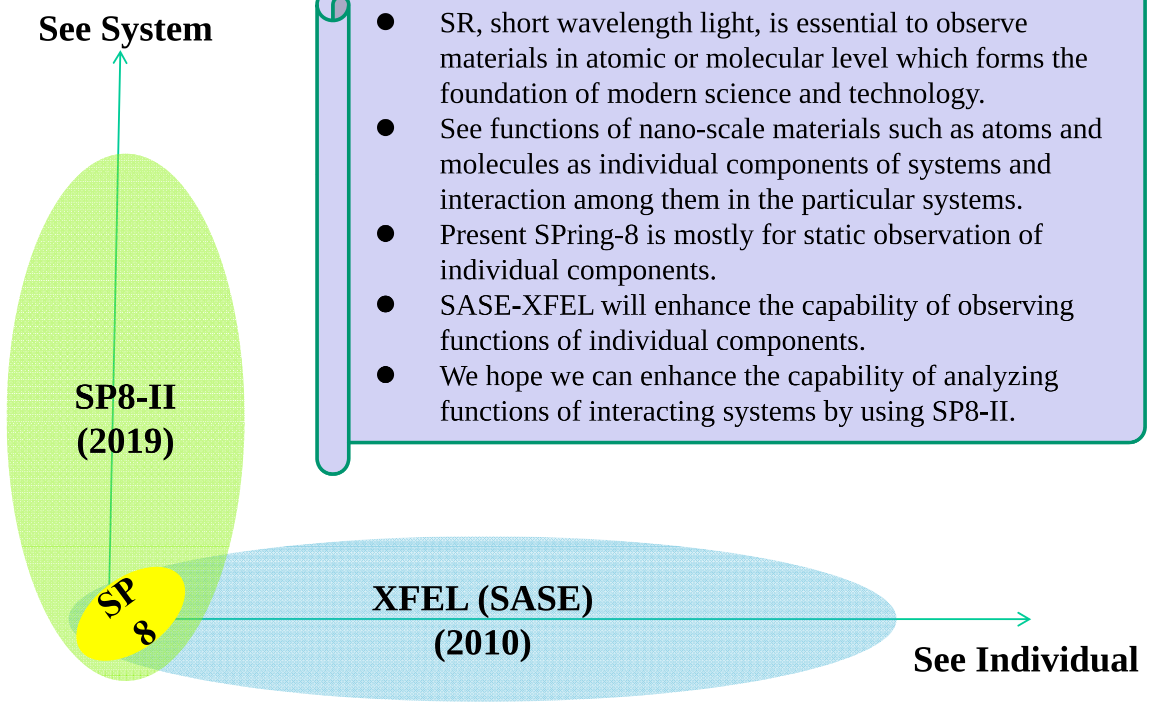
Movie Here

My Personal View; Learning Old, Getting New



Complementary Roles of SR and XFEL

- SR, short wavelength light, is essential to observe materials in atomic or molecular level which forms the foundation of modern science and technology.
- See functions of nano-scale materials such as atoms and molecules as individual components of systems and interaction among them in the particular systems.
- Present SPring-8 is mostly for static observation of individual components.
- SASE-XFEL will enhance the capability of observing functions of individual components.
- We hope we can enhance the capability of analyzing functions of interacting systems by using SP8-II.



Some Tips

- Small or Big ?
- Far or Near ?
- One of you tools or Central Subject ?
- Use your own brain.
- Find what has been not discussed, in reading papers or in listening to lectures.

Summary & Outlook

The future directions are not what you will be taught, but what you yourself shall find or create.

Thank you again for joining us this Cheiron School! We are looking forward to seeing you at some SR facility in near future.