5th AOFSRR School: Cheiron School 2011 (Sept. 26-Oct. 5, 2011)
Spring-8/RIKEN Harima, Hyogo, Japan



Overview of Synchrotron Radiation (SR)

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PAL 포항가속기연구소 POHANG ACCELERATOR LABORATORY

Acknowledgments :

Organizing Committee Members of Cheiron School
Spring-8/JASRI; *Dr. Tetsuhisa Shirakwa*, President
Prof. Masaki Takata
RIKEN Harima Institute
MEXT, Japan
AOFSRR

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Prof. Zhentang Zhao (SSRF, China)
Prof. Tetsuya Ishikawa (RIKEN/Spring-8, Japan)
Prof. Hiroshi Kawata (KEK, Japan)

Outline

1. Introduction
   - AOFSRR / Cheiron School
   - History of SR
   - SR
2. 1st-2nd Generation SR
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AOFSRR

(Asia–Oceania Forum for Synchrotron Radiation Research)

Objectives:

(1) To establish a general framework of collaboration for the development of science and technology, which mutually benefits advancing the research goals of the Parties

(2) To promote comprehensive cooperation in the Asia-Oceania region

(3) To provide education and communication opportunities

- AOFSRR Conference (per year)

1st, 24-25/11/2006, Tsukuba, Japan
2nd , 31/10-02/11/2007, Shinchu, Taiwan
3rd, 4-5/12/2008, Melbourne, Australia
4th, 31/11-02/12/2009/Shanghai, China
5th, 06-09/07/2010/Pohang, Korea
6th, 24-28/10/2011/Bangkok, Thailand

- Cheiron Summer School

1st, 10-19/09/2007, SPring-8, Japan
2nd, 29/09-08/10/2008, Spring-8
3rd, 02-11/11/2009, Spring-8
4th, 09-18/10/2010
5th, 26/09-05/10/2011

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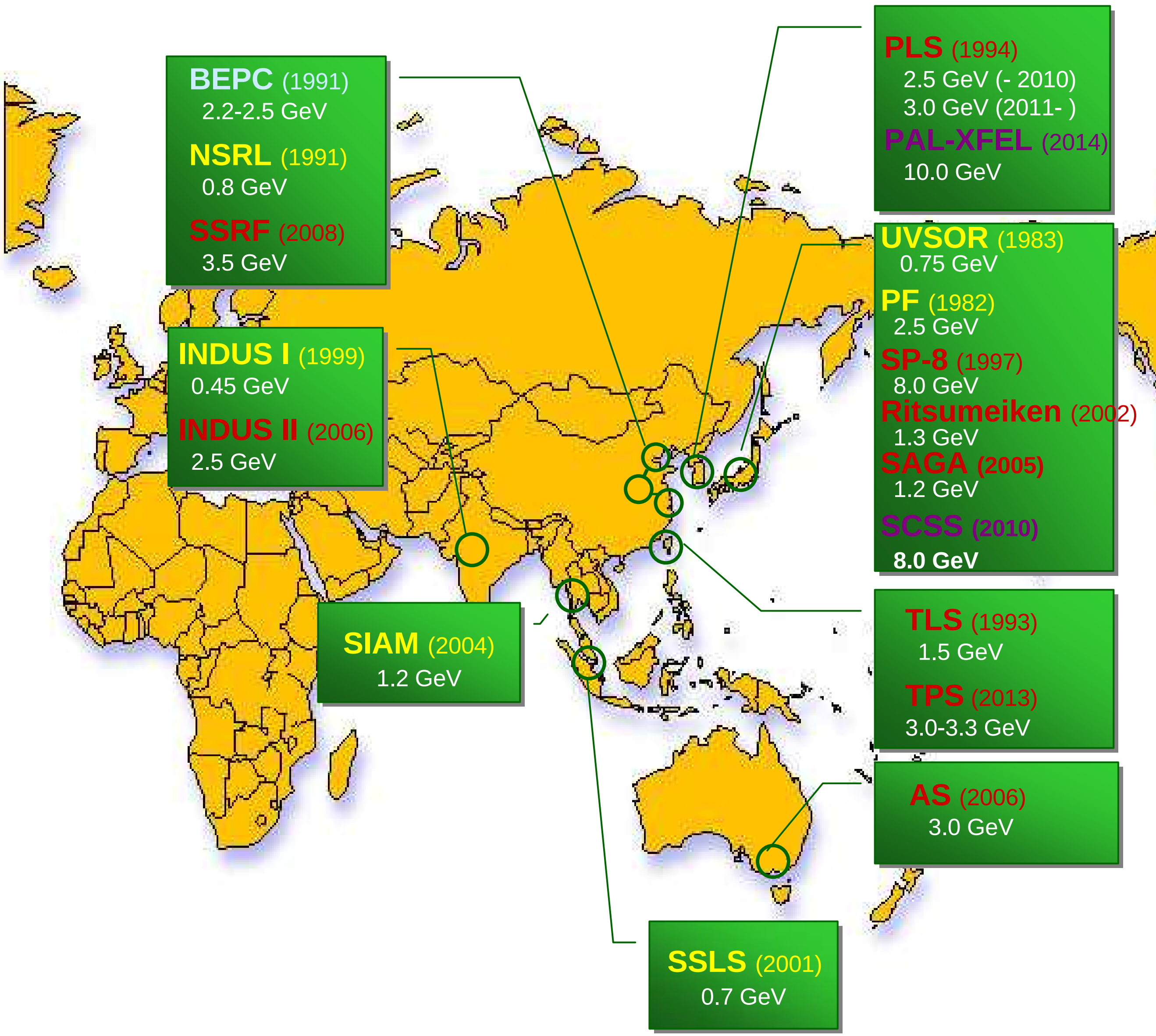
Asia-Oceania Forum for SR Research



July 6-9,2010@Pohang

M. Ree

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Cheiron School 2011 - Program

AOFSRR Cheiron School 2011

Time	Sep.26 Mon.	Time	Sep.27 Tue.	Time	Sep.28 Wed.	Time	Sep.29 Thu.	Time	Sep.30 Fri.	Time	Oct.1 Sat.	Time	Oct.2 Sun.	Time	Oct.3 Mon.	Time	Oct.4 Tue.	Time	Oct.5 Wed.
9:00-10:00	Registration at Public Relations Center (Fukyu-to)	9:00-10:20	Light Souce 2 T. Tanaka (RIKEN)	9:00-10:20	VUV & SX Optics D. Attwood (ALS)	9:00-10:20	Powder Diffraction B. Kennedy (Univ. Sydney)	8:30-21:30	Excursion Kyoto	9:00-10:20	Inelastic Scattering A. Baron (RIKEN)	9:00-10:20	Extreme Conditions G. Shen (APS) / Infrared Tim May (CLS)	9:30-17:30	BL Practical Part 1	9:30-17:30	BL Practical Part 2	9:00-10:20	Advanced Experiments using SR S. Sinha (UCSD)
10:00-10:40	Opening Remarks	10:20-10:40	*Coffee Break*	10:20-10:40	*Coffee Break*	10:20-10:40	*Coffee Break*			10:20-10:40	*Coffee Break*	10:20-10:40	*Coffee Break*					10:20-10:40	*Coffee Break*
10:40-12:00	Overview of SR M. Ree (PAL/PLS)	10:40-12:00	X-ray Beamline Design 1 X-ray Monochromator S. Goto (JASRI)	10:40-12:00	VUV & SX Beamline Design D. Attwood (ALS)	10:40-12:00	Detectors R. Lewis (Monash Univ)			10:40-12:00	Medical Imaging R. Lewis (Monash Univ) / Photoemission (1) Spectroscopy Ku-Ding Tsuei (NSRRC)	10:40-12:00	Small-angle Scattering Y. Amemiya (Univ Tokyo) / Atomic and Molecular Physics K. Ueda (Tohoku Univ)					10:40-12:00	Future of SR T. Ishikawa (RIKEN)
12:00-13:00	*Lunch*	12:00-13:00	*Lunch*	12:00-13:00	*Lunch*	12:00-13:00	*Lunch*			12:00-13:00	*Lunch*	12:00-13:00	*Lunch*					12:00-12:30	Closing Remarks
13:00-14:20	Ring Accelerator Physics H. Tanaka (RIKEN)	13:00-14:20	X-ray Beamline Design 2 Mirror and Multilayer H. Ohashi (JASRI)	13:00-14:20	X-ray Diffraction (Basics) B. Kennedy (Univ. Sydney)	13:00-14:20	Pump-Probe G. Ingold (SLS)			13:00-14:20	Protein Crystallography T. Kumasaka (JASRI) / Soft X-ray Absorption Spectroscopy K. Amemiya (KEK)	13:00-14:20	Discussion with SPring-8 Staff						
14:20-14:40	*Coffee Break*	14:20-14:40	*Coffee Break*	14:20-14:40	*Coffee Break*	14:20-14:30	*Coffee Break*			14:20-14:40	*Coffee Break*	14:20-14:40							
14:40-16:00	Light Souce 1 T. Tanaka (RIKEN)	14:40-16:00	Safety Education	14:40-16:00	XAFS I. Watanabe (Ritsumeikan Univ.)	14:40-16:00	X-ray Microscopy D. Attwood (ALS)			14:40-16:00	X-ray Fluorescence Analysis I. Nakai (Tokyo Sci. Univ) / Photoemission (2) Surface Science I. Matsuda (Univ Tokyo)	14:40-16:00							
16:00-16:20	*Coffee Break*	16:00-16:20	*Coffee Break*	16:00-16:20	*Coffee Break*	16:00-16:20	*Coffee Break*			16:00-16:20	*Move to XFEL* *School Photo*	16:00-16:20							
16:20-17:30	Participants' Self-introduction	16:20-18:00	Site Tour SPring-8	16:20-18:00	Meet the Experts	16:20-18:00	Meet the Experts			16:20-17:40	XFEL H. Tanaka (RIKEN)	16:20-17:40							
										17:40-18:00	Site Tour XFEL								
17:30-18:00	Guest House Check-in	18:00-19:30	*Dinner*	18:00-19:30	*Dinner*	18:00-19:30	*Dinner*			18:00-20:00	Barbecue at Houkou-kan	17:40-19:30	*Dinner*	17:30-19:30	*Dinner*	18:00-19:30	Farewell Reception at Houkou-kan		
18:00-19:30	Welcome Reception at SPS Cafeteria				*SPECTRA T. Tanaka (RIKEN)	19:30-21:00	Tea Ceremony												

"SPECTRA" is a computer software developed at SPring-8 to calculate optical properties of synchrotron radiation emitted from bending magnets, wigglers and undulators.
This workshop is open for those who are interested and will be held only if the number of attendees is larger than 5.

M. Ree

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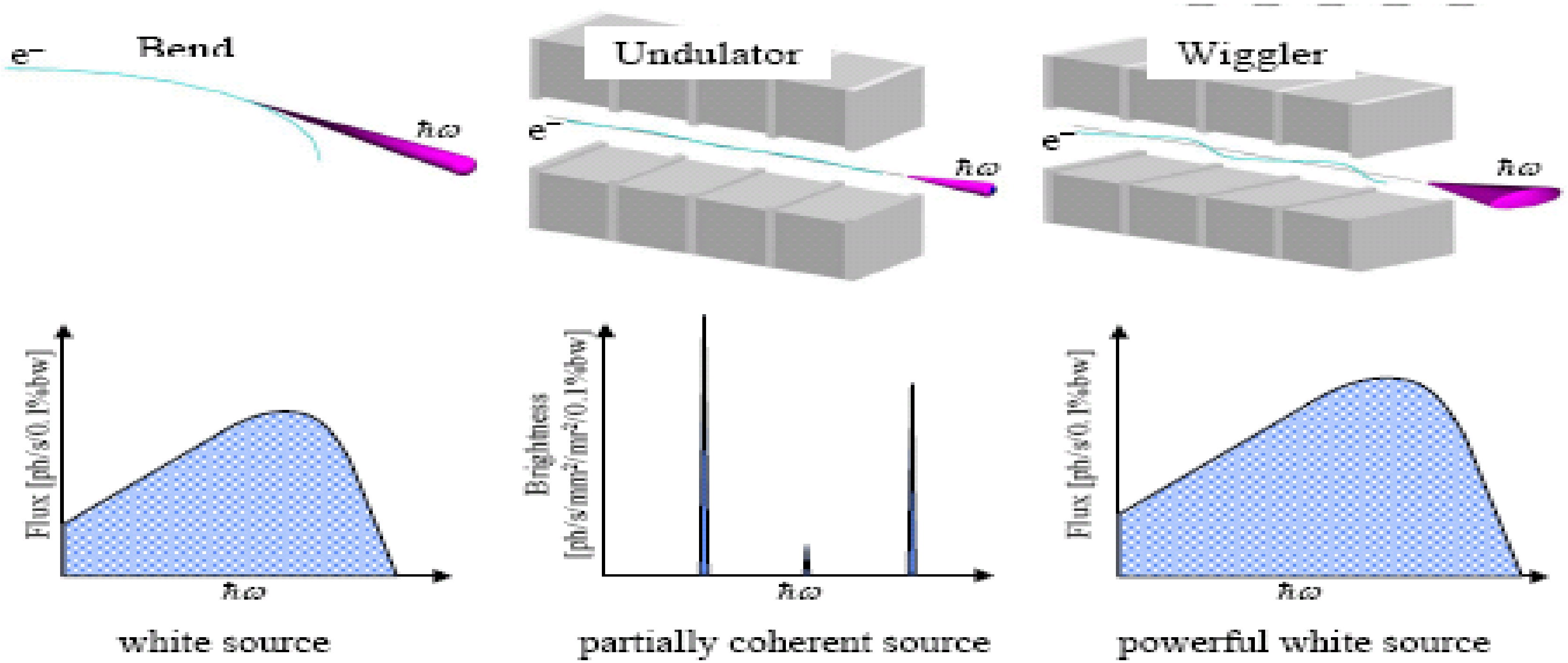
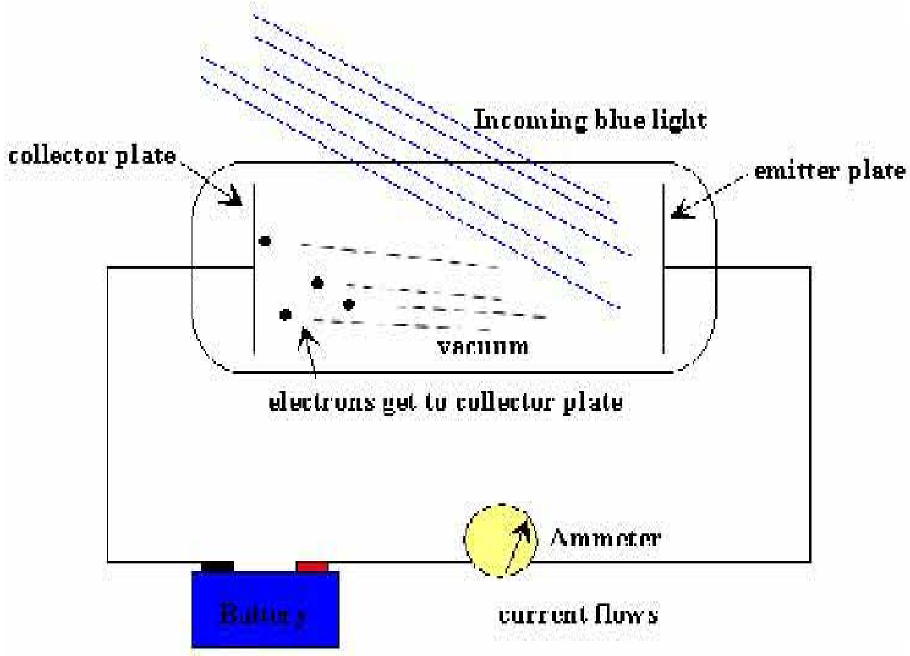
Synchrotron Radiation

- When moving along a curved trajectory in a speed close to that of light, electrons emit electromagnetic radiation in tangential direction.
  This kind of radiation is called synchrotron radiation since it was first observed at a 70 MeV synchrotron radiation machine in 1947.
- The curved trajectory can be created by <u>bending magnet</u>, <u>wiggler</u> and <u>undulator</u> magnets in accelerators.

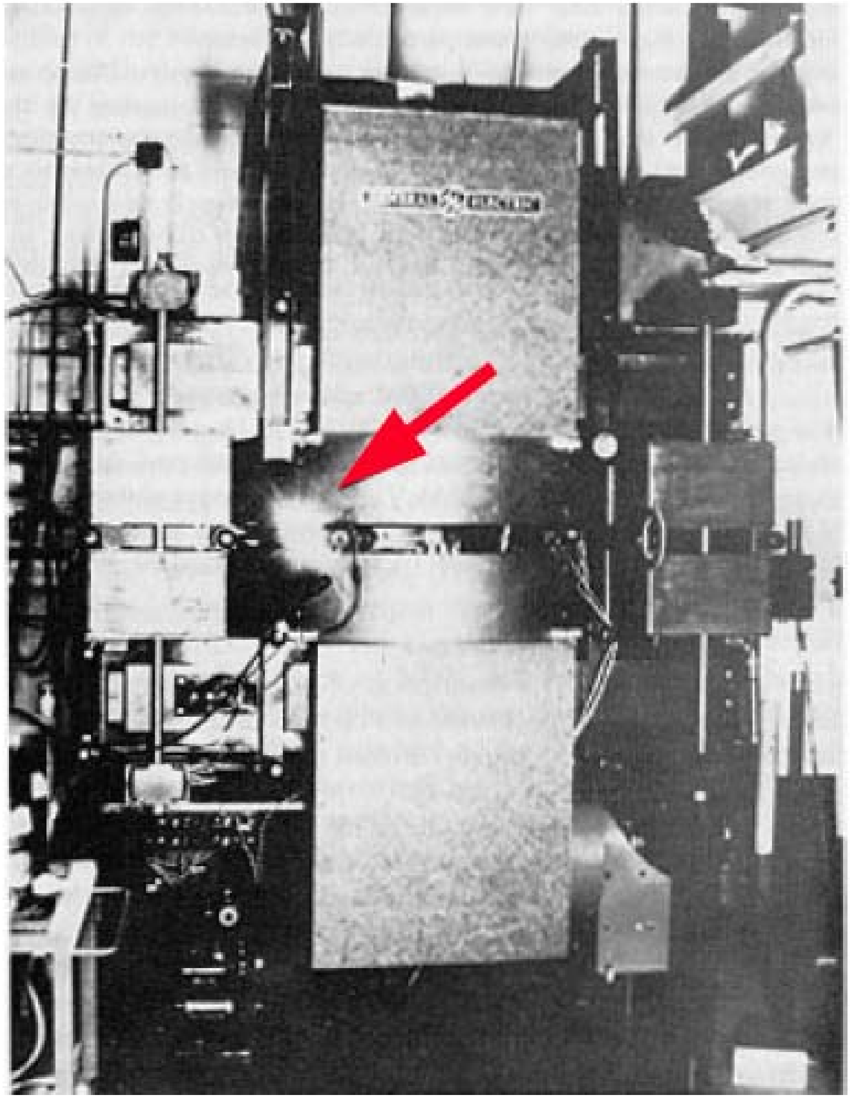




- $e/m = 1.76 * 10^8$ c/g

J.J.Thomson was awarded the 1906 Nobel Prize in Physics for the discovery of the electron and his work on the conduction of electricity in gases.

First Man-Made Synchrotron Radiation Source at GE on Apr. 24, 1947



General Electric betatron built in 1946, the origin of the discovery of Synchrotron radiation.

The radiation was named after its discovery in a General Electric synchrotron accelerator built in 1946 and announced in May 1947 by Frank Elder, Anatole Gurewitsch, Robert Langmuir, and Herb Pollock in a letter entitled "Radiation from Electrons in a Synchrotron." Pollock recounts:

> **"On April 24, Langmuir and I were running the machine and as usual were trying to push the electron gun and its associated pulse transformer to the limit. Some intermittent sparking had occurred and we asked the technician to observe with a mirror around the protective concrete wall. He immediately signaled to turn off the synchrotron as "he saw an arc in the tube." The vacuum was still excellent, so Langmuir and I came to the end of the wall and observed. At first we thought it might be due to Cherenkov radiation, but it soon became clearer that we were seeing Ivanenko and Pomeranchuk radiation."**

First Observation of Synchrotron Radiation from Galaxy (July, 1054)

The Supernova was observed by ancient Korean/Japanese/Chinese astronomers in the year 1054.
The pulsar (a star that spins very fast) produces highly relativistic electrons which themselves produce synchrotron radiation (the bright compact emission) in the magnetic field of the Nebula (a cloud of dusts and gasses; a new star is produced from nebulae).

* *Supernova is an exploding star.*
At least a supernova occurs
per decade in our galaxy.

How a Synchrotron Works

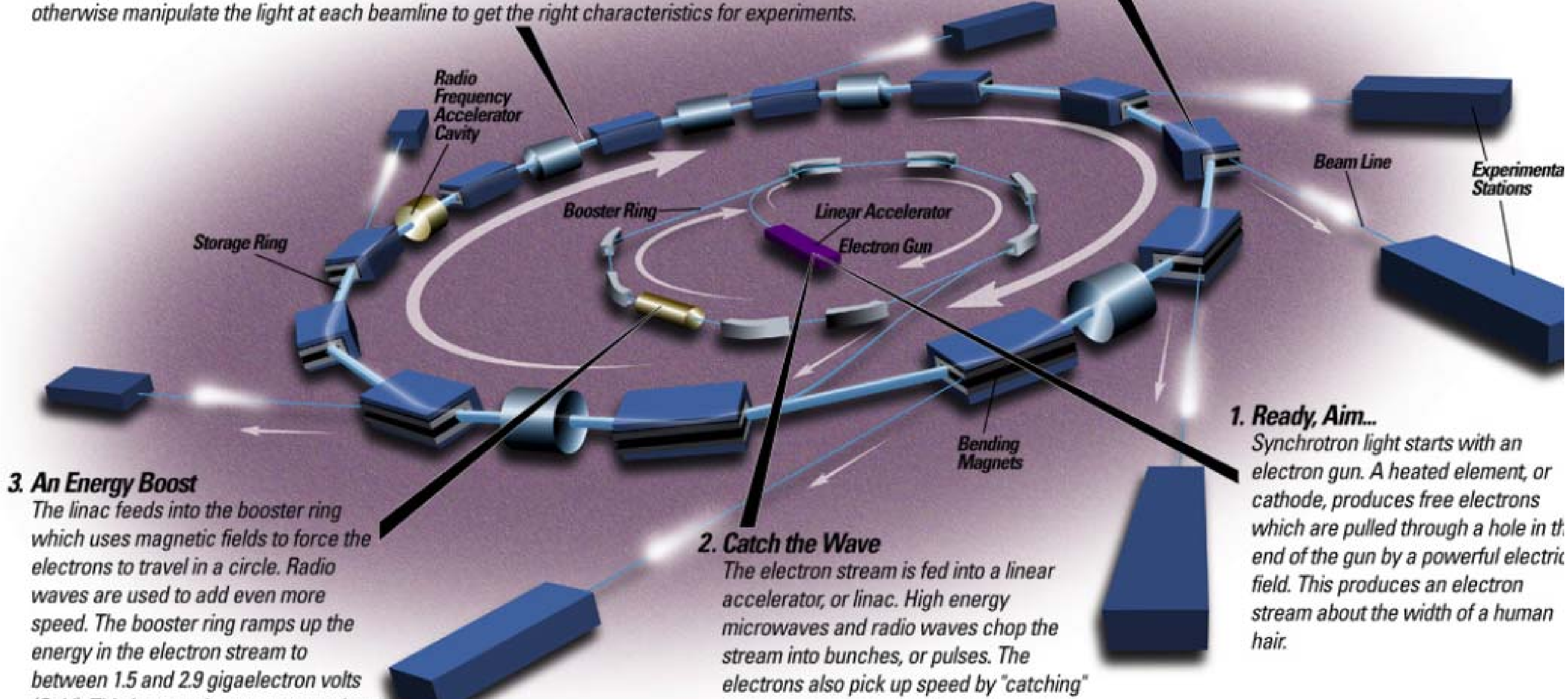
4. Storage Ring

The booster ring feeds electrons into the storage ring, a many-sided donut-shaped tube. The tube is maintained under vacuum, as free as possible of air or other stray atoms that could deflect the electron beam. Computer-controlled magnets keep the beam absolutely true.

Synchrotron light is produced when the bending magnets deflect the electron beam; each set of bending magnets is connected to an experimental station or beamline. Machines filter, intensify, or otherwise manipulate the light at each beamline to get the right characteristics for experiments.

5. Focusing the Beam

Keeping the electron beam absolutely true is vital when the material you're studying is measured in billionths of a metre. This precise control is accomplished with computer-controlled quadrupole (four pole) and sextupole (six pole) magnets. Small adjustments with these magnets act to focus the electron beam.



1. Ready, Aim...

Synchrotron light starts with an electron gun. A heated element, or cathode, produces free electrons which are pulled through a hole in th end of the gun by a powerful electric field. This produces an electron stream about the width of a human hair.

2. Catch the Wave

The electron stream is fed into a linear accelerator, or linac. High energy microwaves and radio waves chop the stream into bunches, or pulses. The electrons also pick up speed by "catching" the microwaves and radio waves. When they exit the linac, the electrons are travelling at 99.99986 per cent of the speed of light and carry about 300 million electron

3. An Energy Boost

The linac feeds into the booster ring which uses magnetic fields to force the electrons to travel in a circle. Radio waves are used to add even more speed. The booster ring ramps up the energy in the electron stream to between 1.5 and 2.9 gigaelectron volts (GeV). This is enough energy to produce synchrotron light in the infrared to hard X-ray range.

Source: University of Saskatchewan
Paradigm Media Group Inc.

Pohang Light Source

2.5 GeV Linac	2.5 GeV Storage Ring	Beamlines and Exp. Stations
		

Beam energy (GeV)	2.5
Rf (MHz)	2856
Klystron power (MW), max	80
Bunch length (ps)	13
Normalized emittance (nm.mrad)	150
Beam current (A)	30
Energy spread (%), fwhm	0.6
Total length (m)	160

Beam energy (GeV)	2.5
Circumference(m)	280.56
Natural emittance (nm)	18.9
Rf (MHz)	500.082
Rf voltage (MV)	1.6
Tunes	14.28/8.18
Super-periods	12

30 B/L (9 IDs)
1 FEL (THz BL)

10 B/L (in plan)

41 (Total)
52 (in full capacity)

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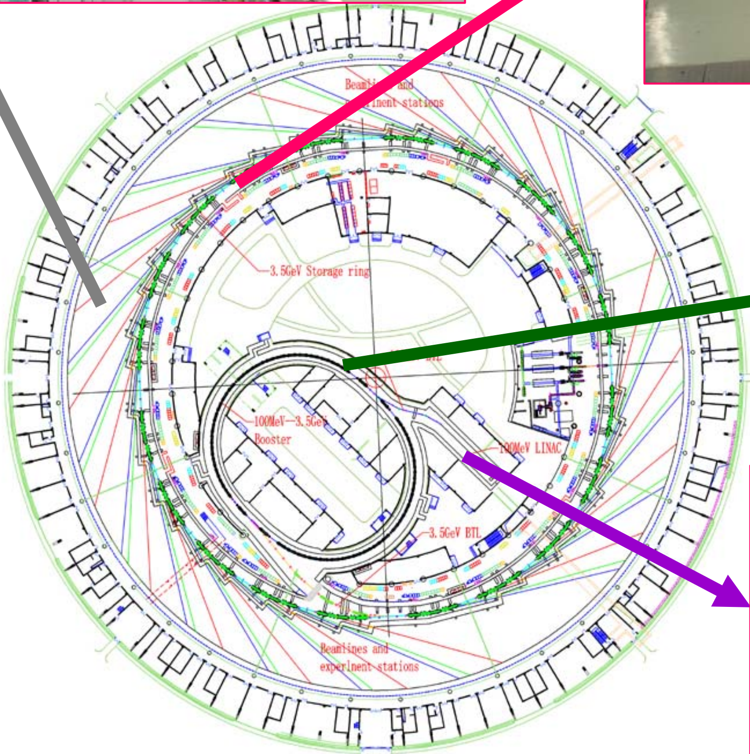
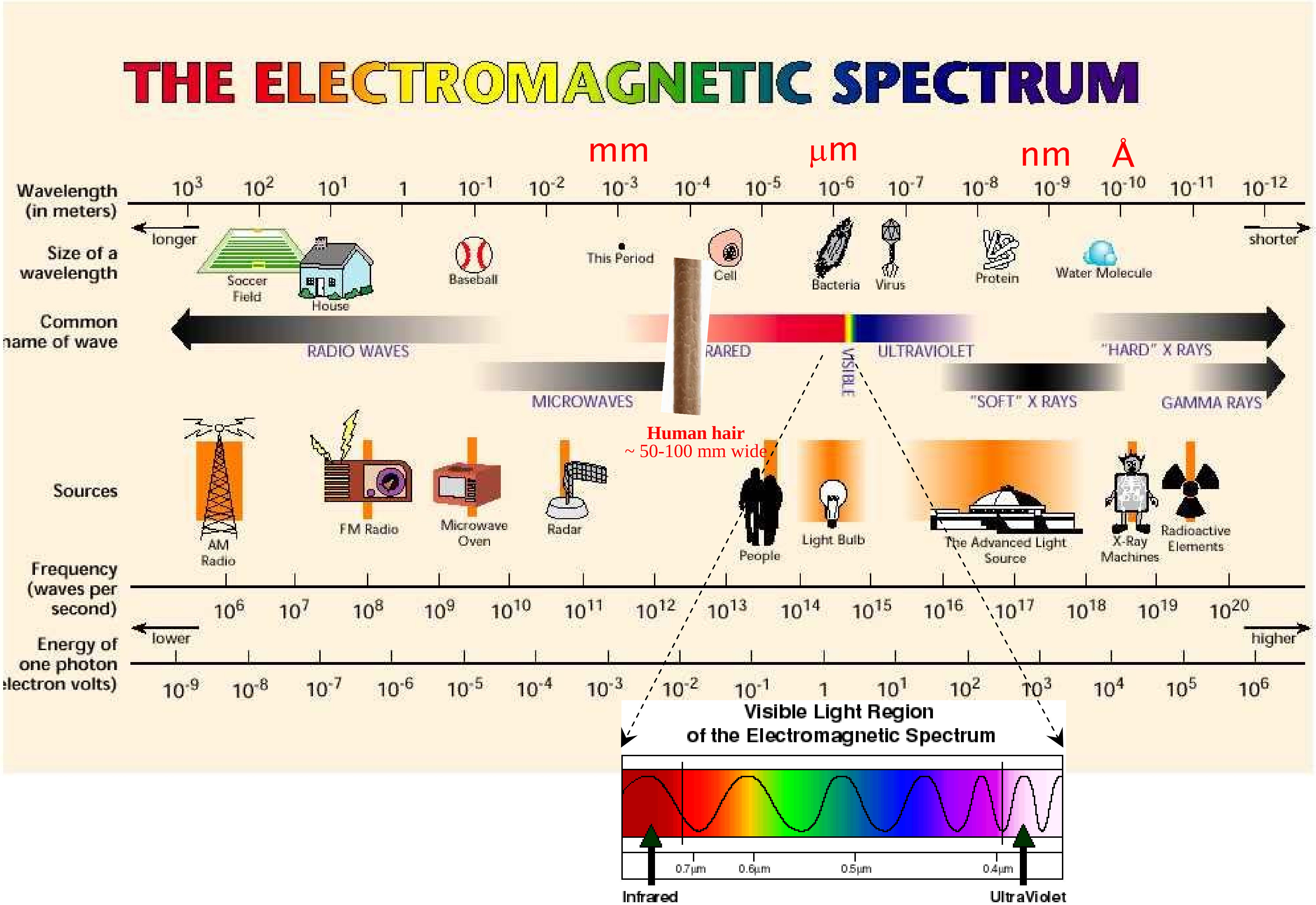
Shanghai Light Source

Storage Ring
3.5GeV, C=432m



Booster
3.5GeV, C=180m

Electron Linac
150MeV


THE ELECTROMAGNETIC SPECTRUM
mm
µm
nm
Å
Wavelength (in meters)
10^3 10^2 10^1 1 10^-1 10^-2 10^-3 10^-4 10^-5 10^-6 10^-7 10^-8 10^-9 10^-10 10^-11 10^-12
longer
shorter
Size of a wavelength
Soccer Field
House
Baseball
This Period
Cell
Bacteria
Virus
Protein
Water Molecule
Common name of wave
RADIO WAVES
INFRARED
VISIBLE
ULTRAVIOLET
"HARD" X RAYS
MICROWAVES
"SOFT" X RAYS
GAMMA RAYS
Human hair
~ 50-100 mm wide
Sources
AM Radio
FM Radio
Microwave Oven
Radar
People
Light Bulb
The Advanced Light Source
X-Ray Machines
Radioactive Elements
Frequency (waves per second)
10^6 10^7 10^8 10^9 10^10 10^11 10^12 10^13 10^14 10^15 10^16 10^17 10^18 10^19 10^20
lower
higher
Energy of one photon (electron volts)
10^-9 10^-8 10^-7 10^-6 10^-5 10^-4 10^-3 10^-2 10^-1 1 10^1 10^2 10^3 10^4 10^5 10^6
Visible Light Region of the Electromagnetic Spectrum
0.7µm
0.6µm
0.5µm
0.4µm
Infrared
UltraViolet

Properties of Synchrotron Radiation

- Broad spectrum: from infrared to hard X-ray;
- Wide tunability in photon energy (or wavelength) by monochromatization: sub eV up to the MeV Range;
- High Brilliance and high flux: many orders of magnitude higher than that with the conventional X-ray tubes;
- Highly collimated: radiation angular divergence angle proportions inversely to electron beam energy (1/ γ);
- High level of polarizations: linear, circular, elliptical;
- Pulsed time structures: tens of picoseconds pulse;
- …

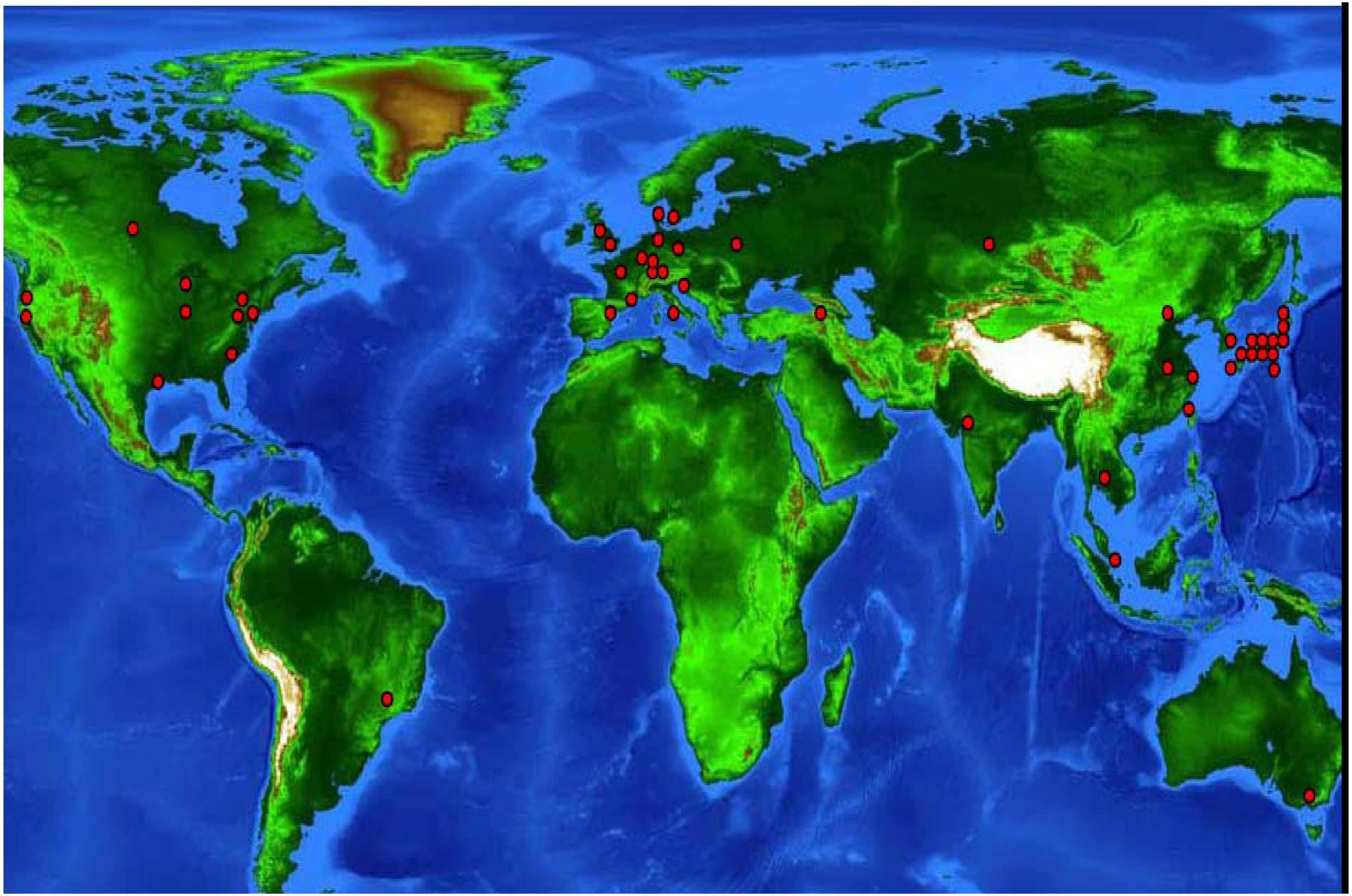
Synchrotron Radiation Facilities

- Over the past 30 years, design and construction of dedicated SR facilities have been continuously carried out all over the world. Currently there are about 50 SR light sources in operation and about 22 of them are third generation light sources;

- Before 1970s, first generation light sources, attached to high energy machines, were parasitically operated;
- From the mid-1970s to the late 1980s, second generation light sources were designed and constructed as dedicated SR user facilities;
- From the mid-1980s, third generation light sources have been designed and constructed with low emittance beam and undulators;
- Since the Mid-1990s, the construction of intermediate energy third generation light sources has been the focus of efforts worldwide;
- Meanwhile compact synchrotron radiation facilities have been designed and constructed.

Synchrotron Radiation Facilities (in operation)

Asia-Oceania : 26   Europe : 25   America : 18



www.lightsources.org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Melbourne

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5. Summary & Conclusions

1st Generation SR Facilities (1)

1st Generation?

Synchrotron light sources were basically beamlines built onto the existing facilities designed for particle physics studies.

Facility	Location	Energy (GeV)	Operation Year (Status)
VEPP-2M	Russia	0.7	1965-1999 (Upgraded)
SPEAR-I(SSRL)	USA	3.0-3.5	1972-1992 (Upgraded)
DORIS(DESY)	Germany	3.7-5.2	1974-1993 (Upgraded)
SURF-II(NBS)	USA	0.28	1974-1997 (Upgraded)
Accum.Ring(KEK)	Japan	6.5	Partly Ded.
CESR(CHESS)	USA	5.5	1979-2002 (Upgraded)
VEPP-3(INP)	Russia	2.2	1979-1985 (Upgraded)
ELSA	Germany	1.5-3.5	1987 (Operation)
TRISTAN MR	Japan	6.0-30	1987-1995 (Shutdown)
BEPC(IHEP)	China	1.5-2.8	1989-2004 (Upgraded)
DCI(LURE)	France	1.8	Dedicated

1st Generation SR Facilities (2)

Facility	Location	Energy (GeV)	Operation Year (Status)
ASTRID	Denmark	0.6	1990 (Operation)
VEPP-4	Russia	5.0-7.0	1994 (Operation)
DAΦNE	Italy	0.51	1999 (Operation)
TSSR	Japan	1.5	Proposed
AmPS	Netherland	0.9	Planned use
EUTERPE	Netherland	0.4	Planned use
N-100	Russia	2.2	Dedicated
HP-2000	Russia	5.5	Partly Ded.

2nd Generation SR Facilities (1)

2nd Generation?

Synchrotron light sources were dedicated to the production of synchrotron radiation and employed electron storage rings to harness the synchrotron light.

Facility	Location	Energy (GeV)	Operation Year (Status)
SOR-Ring	Japan	0.38	1974-1997 (Shutdown)
Aladdin	USA	0.8-1.0	1977 (Operation)
SRS(Daresbury)	UK	2.0	1981-2008 (Decommissioned)
NSLS-I	USA	0.75	1982 (Operation)
PF(KEK)	Japan	2.5-3.0	1983 (Operation)
UVSOR	Japan	0.75	1983-2003 (Upgraded)
MAX(LTH)	Sweden	0.55	1986 (Operation)
BESSY I	Germany	0.8	1987-1999 (Decommissioned)
HESYRL(USTC)	China	0.8	1991 (Operation)
PETRA-II	Germany	7.0-13	1995-2009 (Decommissioned)
LNLS-I	Brazil	1.15	1997 (Operation)
INDUS-I	India	0.45	1999 (Operation)

2nd Generation SR Facilities (2)

Facility	Location	Energy (GeV)	Operation Year (Status)
TERAS	Japan	0.8	Dedicated
Siberia-I	Russia	0.45	Dedicated
TNK	Russia	1.2-1.6	Dedicated
CAMD	USA	1.2	(Operation)

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5. Summary & Conclusions

3rd Generation Light Sources

- 3rd generation light sources, based on advanced undulators, Wigglers, and low emittance storage ring, are currently then main working horses. According to the storage ring energy, it can be classified into low-, high- and intermediate energy light sources;

- High energy third generation light sources (>4GeV)：ESRF, APS, Spring-8;

- Low energy ones (<2.5GeV): ALS, Elettra, TLS, BESSY-II, MAX-II, LNSL, … ;

- Intermediate energy ones (2.5 ~ 4.0GeV): PLS, ANKA, SLS, CLS, SPEAR3, Diamond, SOLEIL, INDUS-II , ASP, SSRF, ALBA, NSLS-II, TPS, MAX-IV, … ;

- In addition, further advanced third generation light sources, diffraction limited or ultimate, are under investigations and studies. Notably, progress is very encouraging in upgrading the high energy physics accelerators into advanced third generation light sources, such as the PETRA-III in operation at DESY and the PEP-X proposal at SLAC.

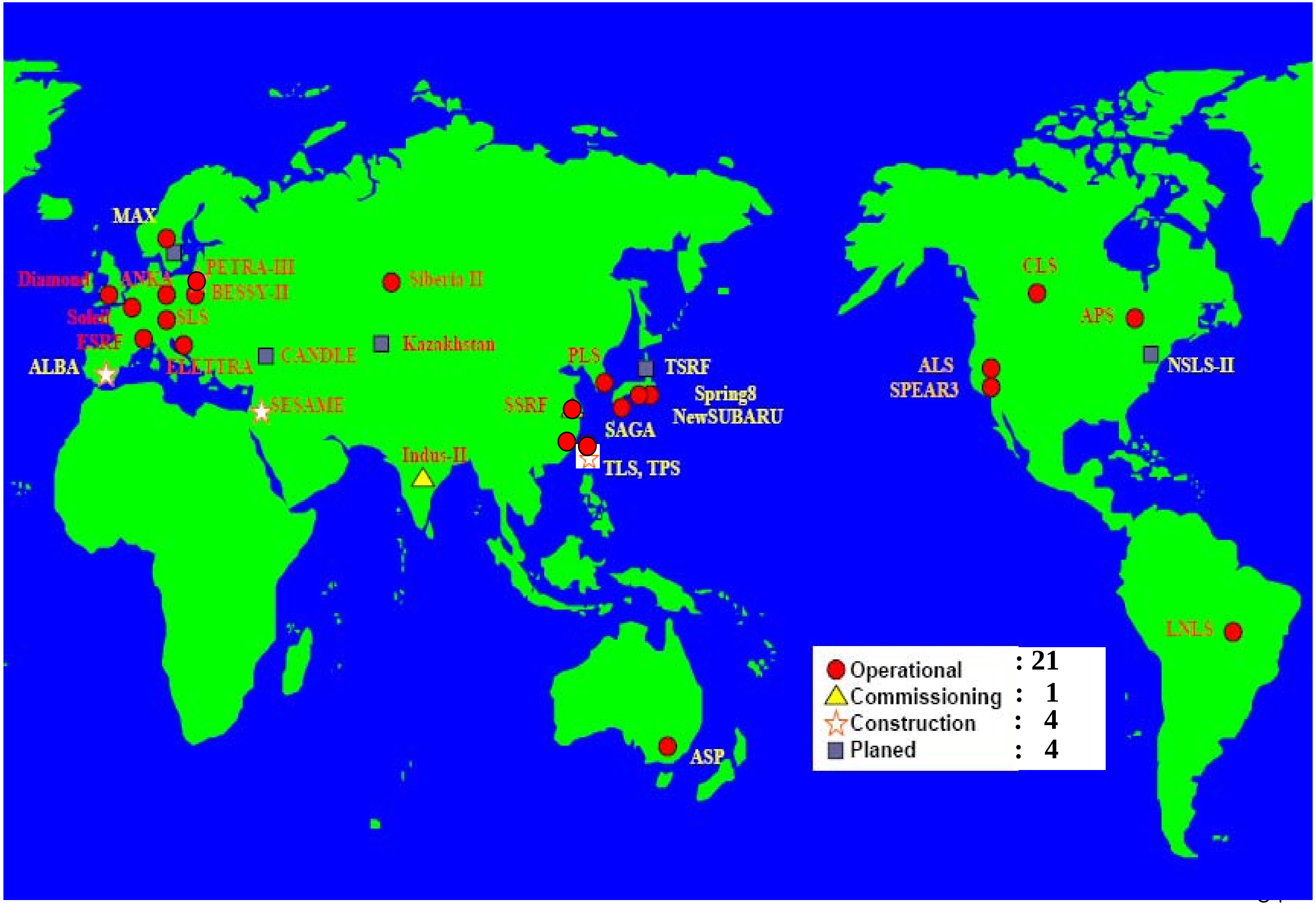
Intermediate Energy Light Sources

- The pioneering third generation light sources generated bright radiation based on fundamental and lowest harmonic spectral line of undulator:
  - High energy machines were optimized at 5-25keV for hard X-ray science;
  - Low energy ones were designed &optimized for VUV and soft X-ray sciences;
- As undulator technology well developed, its theoretical brilliance can be achieved at higher harmonics, this leads to a few of outstanding properties of intermediate energy light sources;
  - The photon beam properties in the 5-25keV range generated with intermediate energy light sources are comparable with those from high energy machines;
  - Up to 11th-15th harmonics are currently used at operating machines;
  - Circumference ranges from 100^{+}m to ~800m depending on budget;
  - Low construction and operation costs make it a cost effective light source right for meeting the regional needs;

Intermediate Energy SR Facilities

- Since the beginning of 21st century, intermediate energy light sources have been being successively put into operation;
- SLS in 2001, ANKA in 2002, CLS in 2003, SPEAR3 in 2004, SAGA-LS in 2005, and another five, ASP, Diamond and SOLEIL in 2007, SSRL in 2009, and ALBA in 2010;
- One more will be operational in the coming years, SESAME probably in 2013;
- NSLS-II, TPS and MAX-IV may start operation before 2015;
- Other intermediate light source plans are under consideration or R&D in countries including Armenia (CANDLE), Poland and South Africa;
- Some new proposals are still appearing, including a new one in China;

3rd Generation Light Sources around the World



3^{rd} Generation Light Sources in Operation (1)

Light Source	Energy (GeV)	Circumference (m)	Emittance (nm.rad)	Current (mA)	Straight Section	Status
1. ALS	1.9	196.8	6.3	400	12×6.7m	Operation (1993)
2. ESRF	6.0	844.4	3.7	200	32×6.3m	Operation (1993)
3. TLS	1.5	120	25	240	6×6m	Operation (1993)
4. ELETTRA	2.0/2.4	259	7	300	12×6.1m	Operation (1994)
5. PLS (in upgrading)	2.5 (3.0)	280.56	18.6 (5.8)	200 (400)	12×6.8m (+ 12x4.2m)	Operation (1995) (2011)
6. APS	7.0	1104	3.0	100	40×6.7m	Operation (1996)
7. SPring-8	8.0	1436	2.8	100	44×6.6m, 4×30m	Operation (1997)
8. LNLS	1.37	93.2	70	250	6×3m	Operation (1997)
9. MAX-II	1.5	90	9.0	200	10×3.2m	Operation (1997)
10. BESSY-II	1.7	240	6.1	200	8×5.7m, 8×4.9m	Operation (1999)
11. Siberia-II	2.5	124	65	200	12×3m	Operation (1999)
12. NewSUBARU	1.5	118.7	38	500	2×14m, 4×4m	Operation (2000)

3rd Generation Light Sources in Operation (2)

Light Source	Energy (GeV)	Circumference (m)	Emittance (nm.rad)	Current (mA)	Straight Section	Status
13. SLS	2.4-2.7	288	5	400	3×11.7m, 3×7m, 6×4m	Operation (2001)
14. ANKA	2.5	110.4	50	200	4×5.6m, 4×2.2m	Operation (2002)
15. CLS	2.9	170.88	18.1	500	12×5.2m	Operation (2003)
16. SPEAR-3	3.0	234	12	500	2×7.6m,4×4.8m, 12×3.1m	Operation (2004)
17. SAGA-LS	1.4	75.6	7.5	300	8×2.93m	Operation (2005)
18. ASP	3.0	216	7-16	200	14×5.4m	Operation (2007)
19. DIAMOND	3.0	561.6	2.7	300	6×8m, 18×5m	Operation (2007)
20. SOLEIL	2.75	354.1	3.74	500	4×12m, 12×7m, 8×3.8m	Operation (2007)
21. SSRF	3.0	432	3.9	300	4×12m, 16×6.5 m	Operation (2009)

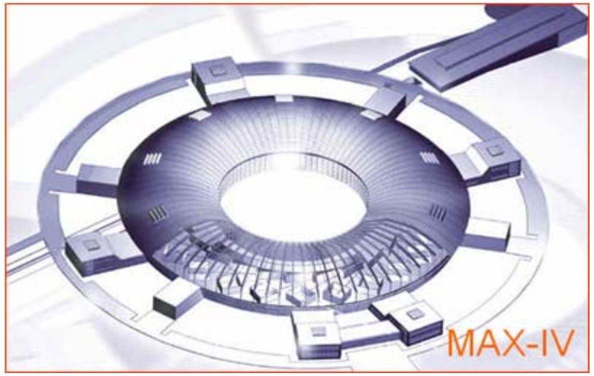
3rd Generation Light Sources in Operation (1)

New 3rd Generation Light Sources in Operation (2)

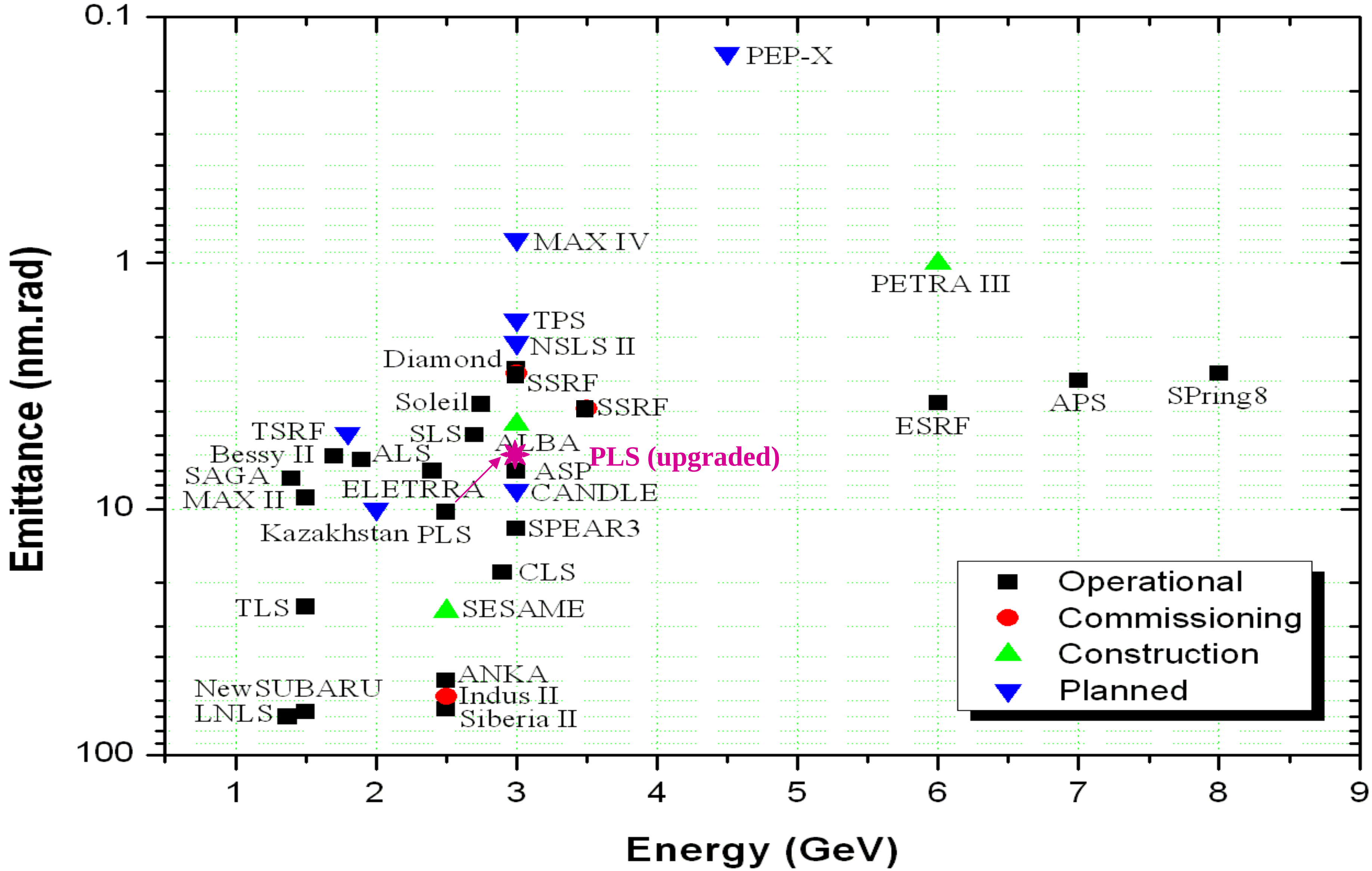
New 3rd Generation Light Sources
in Commissioning, Construction and Plan

Light Source	Energy (GeV)	Circumference (m)	Emittance (nm.rad)	Current (mA)	Straight Section	Status
22. Indus-2	2.5	172.5	58	300	8×4.5m	Commi.&Opera.
23. PETRA-III	6.0	2304	1.0	100	1×20m, 8×5m	Construction (commissioning in 2010)
24. ALBA	3.0	268.8	4.5	400	4×8m, 12×4.2m, 8×2.6m	Construction
25. SESAME	2.5	133.12	26	400	8×4.44m, 8×2.38 m	Construction
26. TPS	3.0	518.4	1.6	400	6×12m, 18×7m	Construction
27. CANDLE	3.0	216	8.4	350	16×4.8m	Planned
28. NSLS-II	3.0	792	2.1	500	15×9.3m, 15×6.6 m	Planned
29. MAX IV	3.0	287.2	0.8	500	12×4.6m	Planned
30. TSRF	TBD	TBD	TBD	TBD	TBD	Planned

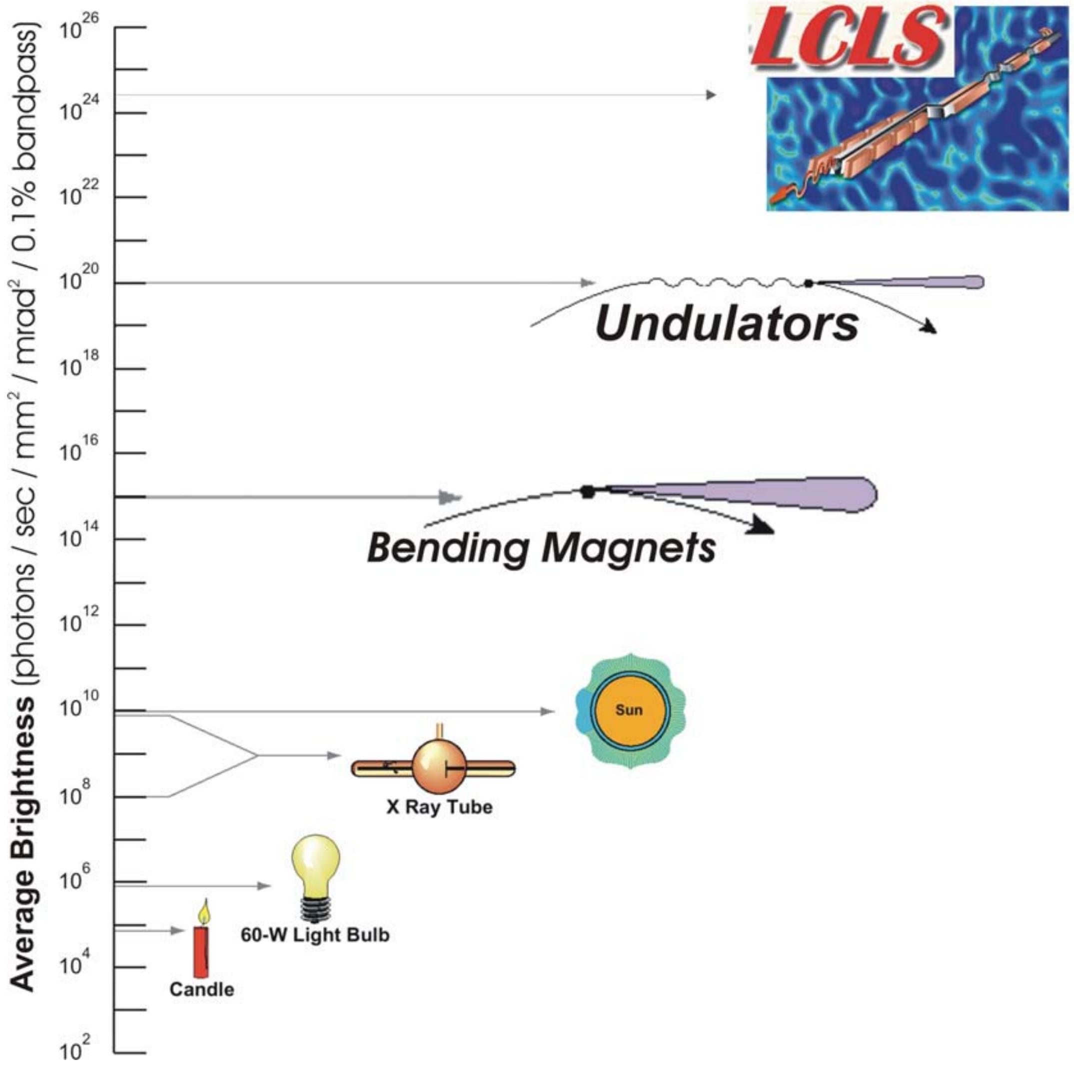
New 3rd Generation Light Sources

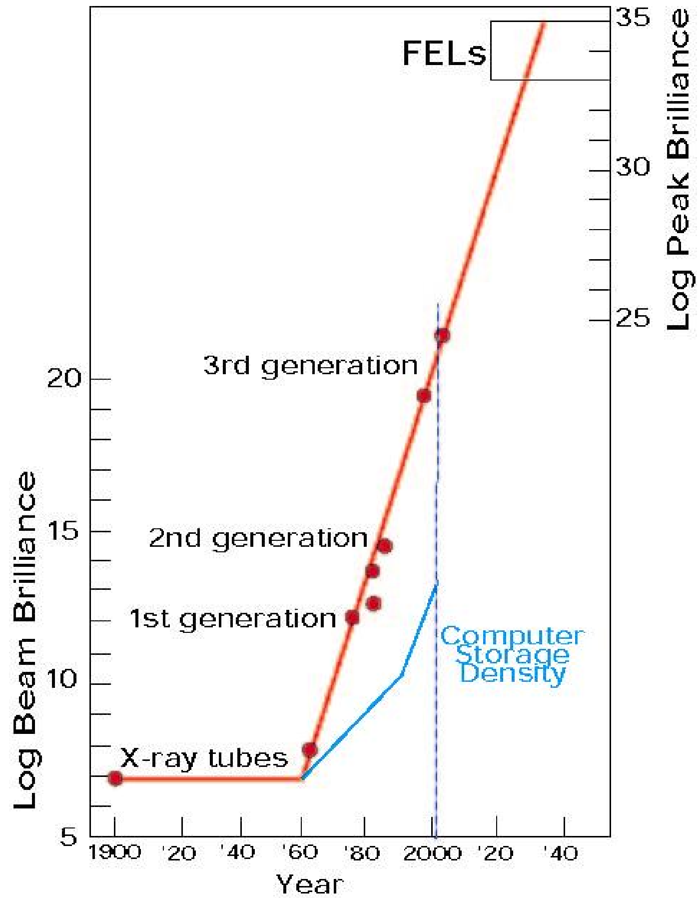


Third Generation Light Sources



Brilliance Improvement





Main Figures of Merit of 3rd Generation Light Sources

- **Undulator average spectral brilliance**
  - Emittance;
  - Beam current;
  - Energy spread;
- **Beam quality**
  - Beam position stability;
  - Intensity stability;
  - Energy stability;
  - Beam lifetime;
  - Availability, reliability and MTBF
- **Time structured and polarized radiation**
  - Bunch fill patterns and short bunch schemes;
  - Various ID applications;

Third Generation Light Sources

❑ **Properties of third generation light sources;**

- **Higher brilliance: up to 10^{17}~10^{21}photons/s/mm^2/mrad^2/0.1%BW;**
- **Higher flux: up to 10^{15}~10^{17}photons/s/0.1%BW;**
- **Sub-micro orbit stability: beam position and divergence stability down to submicron and sub-microradian;**
- **Large number and various kinds of insertion devices: EU, PMW, PMU, EPU, HU, INVU, CPMU, SW, SU, …;**
- **Top-up operation: keeping operating current constant at 0.1-1% level;**
- **Partially coherent (vertical direction): vertical diffraction limited;**
- **Short pulse radiation: picoseconds to sub-picoseconds;**
- **High reliability-availability operation: availability is better than 95%;**
- **Ultra-low emittance: pushing for 1 nm-rad emittance by using damping wigglers**

3rd Generation Light Source

- **~ 2.0 GeV is the boarder line for VUV and X-ray machines;**

(Note that 800 MeV vs. 2.5 GeV at NSLS)

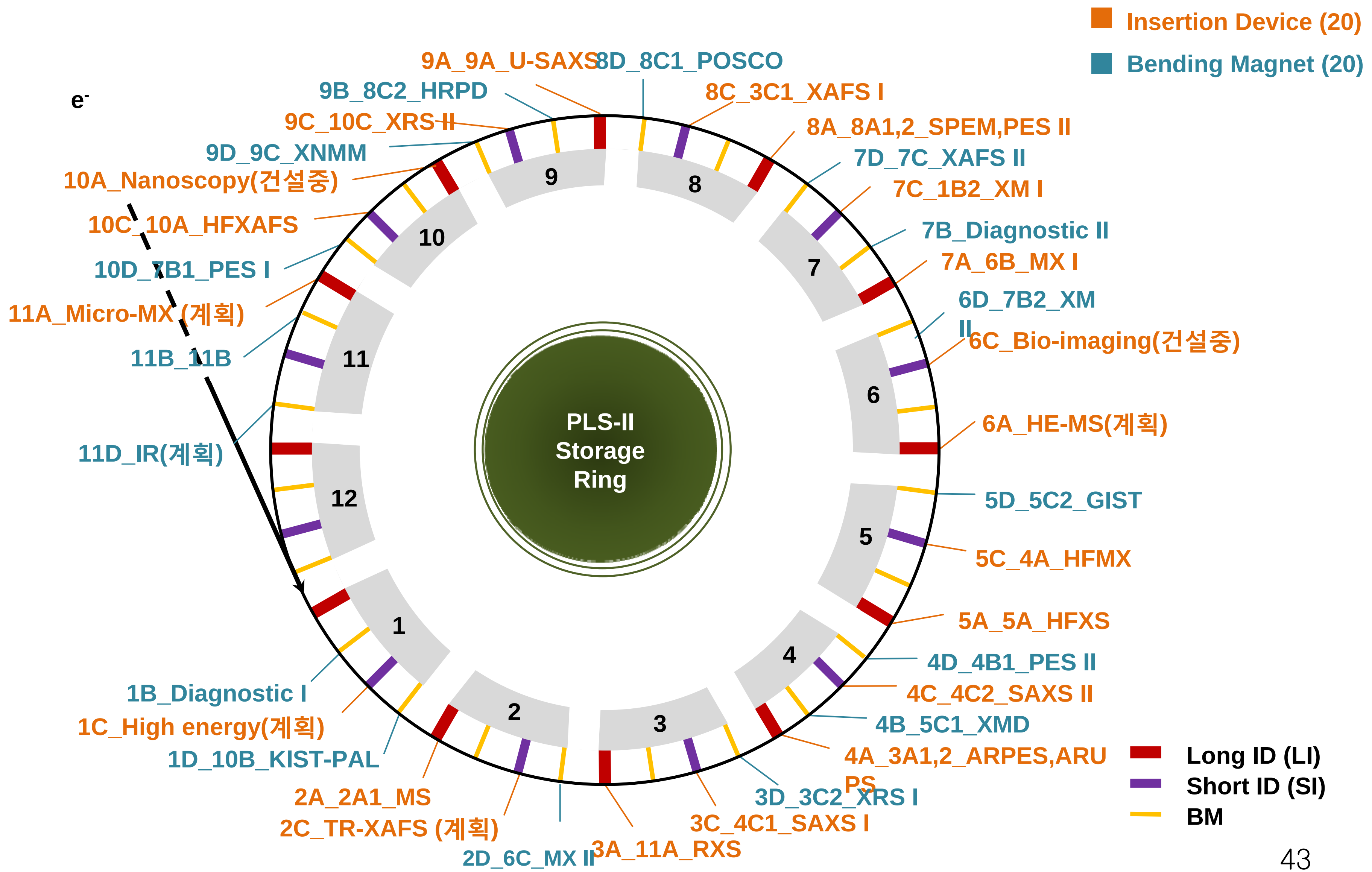
- **User number : ~ 20% (VUV) vs. 80% (X-ray)**

- **Required beam time /Experiment :**

  ~ 80 % (VUV) vs. 20 % (X-ray)

Beamines & Science

PLS-II



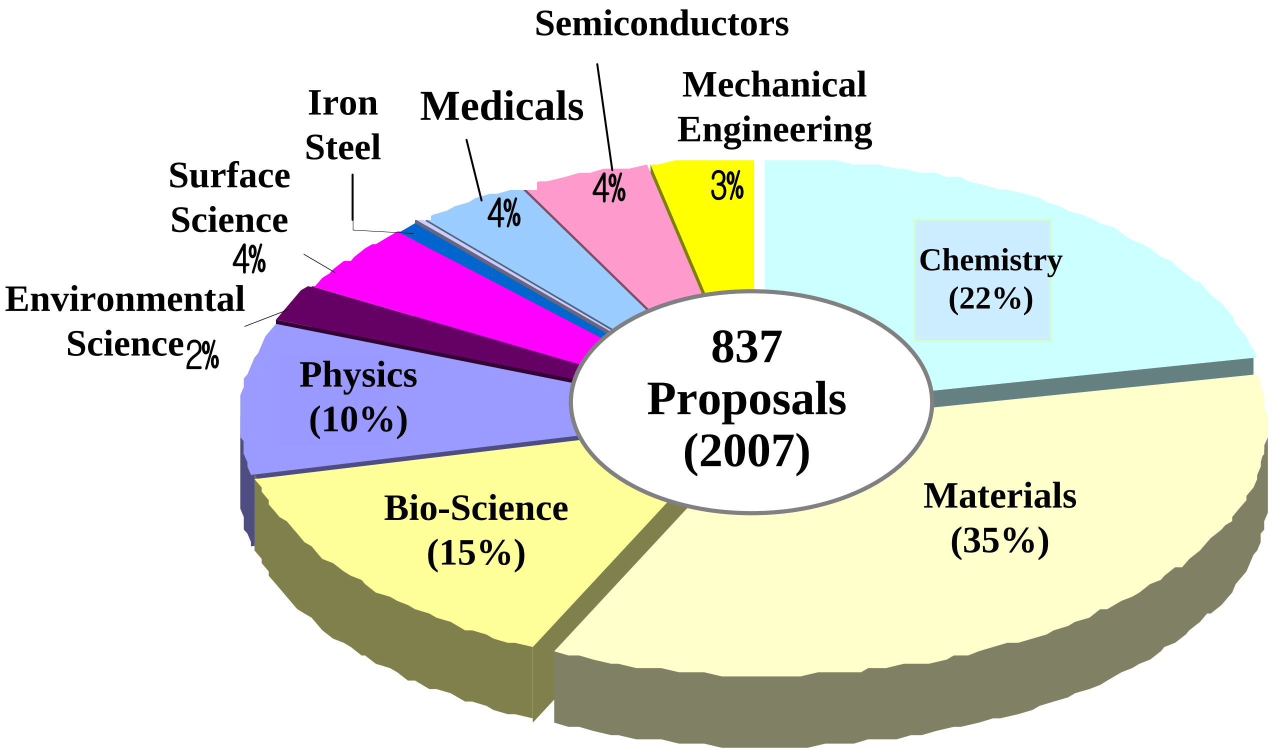
SR Applications in Science

- Spatial Science vs. Time-Domain Science
- Spectroscopy Science
- Scattering Science
- Microscopy (Imaging) Science
- Science & Technology Fields:

Physics, Chemistry, Materials , Biology, Medicine, Pharmaceutics, Environmental, Agriculture, Information Technology, Displays, Mechanical Engineering ……….

(almost all fields of Science and Technology)

Applications of PLS in Science and Industry



Users' publications: ca. 900

Average Impact Factor: 3.8

Accepted Proposals/year:	**800-850**
Acceptance Rate/year:	**50-70%**
Users/year:	**3,000**
	(came to PLS for exps.)

- **There are dramatic increased demands from life science research, for example, big three statistics (ESRF, APS, Spring-8) in structural biology.**

- **One may note that cases of PLS and TLS are also outstanding results.**

- **The overall users are about 100,000 in the world.**

ESRF Scientific Output

863 refereed publications in 2000
(registered – > 85% are “real”ESRF publications)

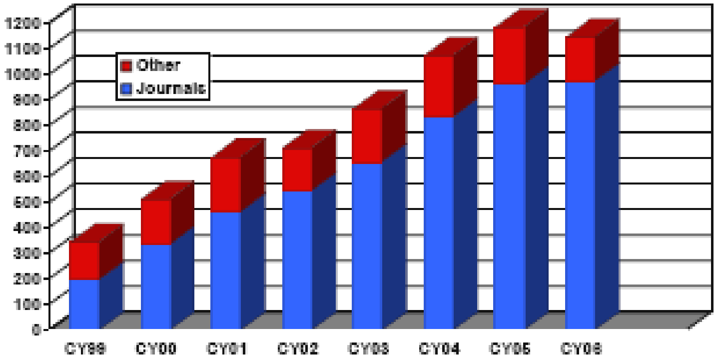
1201 refereed publications in 2001 (registered)
~ 40 papers in NATURE and SCIENCE
~ 50 papers in Physical Review Letters/Europhysics Letters
~ 90 papers in Physical Review

1106 refereed publications in 2002 (registered)

1206 refereed publications in 2003 (registered)

APS scientific impact increasing (by the numbers)

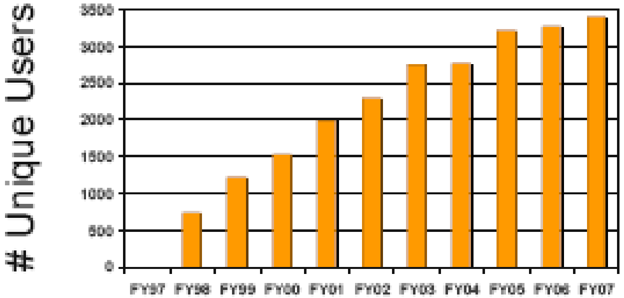
Refereed publications



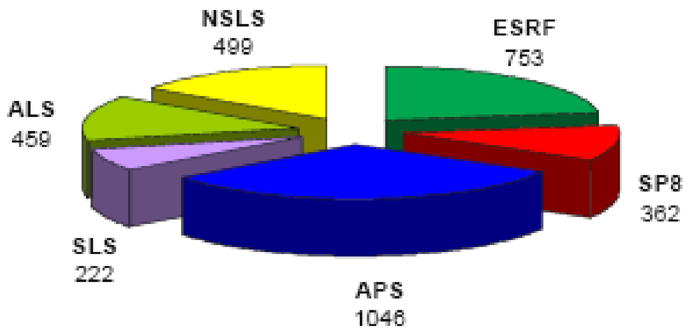
Selected high-impact stats

	2004	2005	2006
Cell	7	6	14
All *Nature*	32	37	37
PRL	21	27	37
Science	11	9	20
PNAS	33	44	43

58% journal papers with impact factor >3.5 (2006)

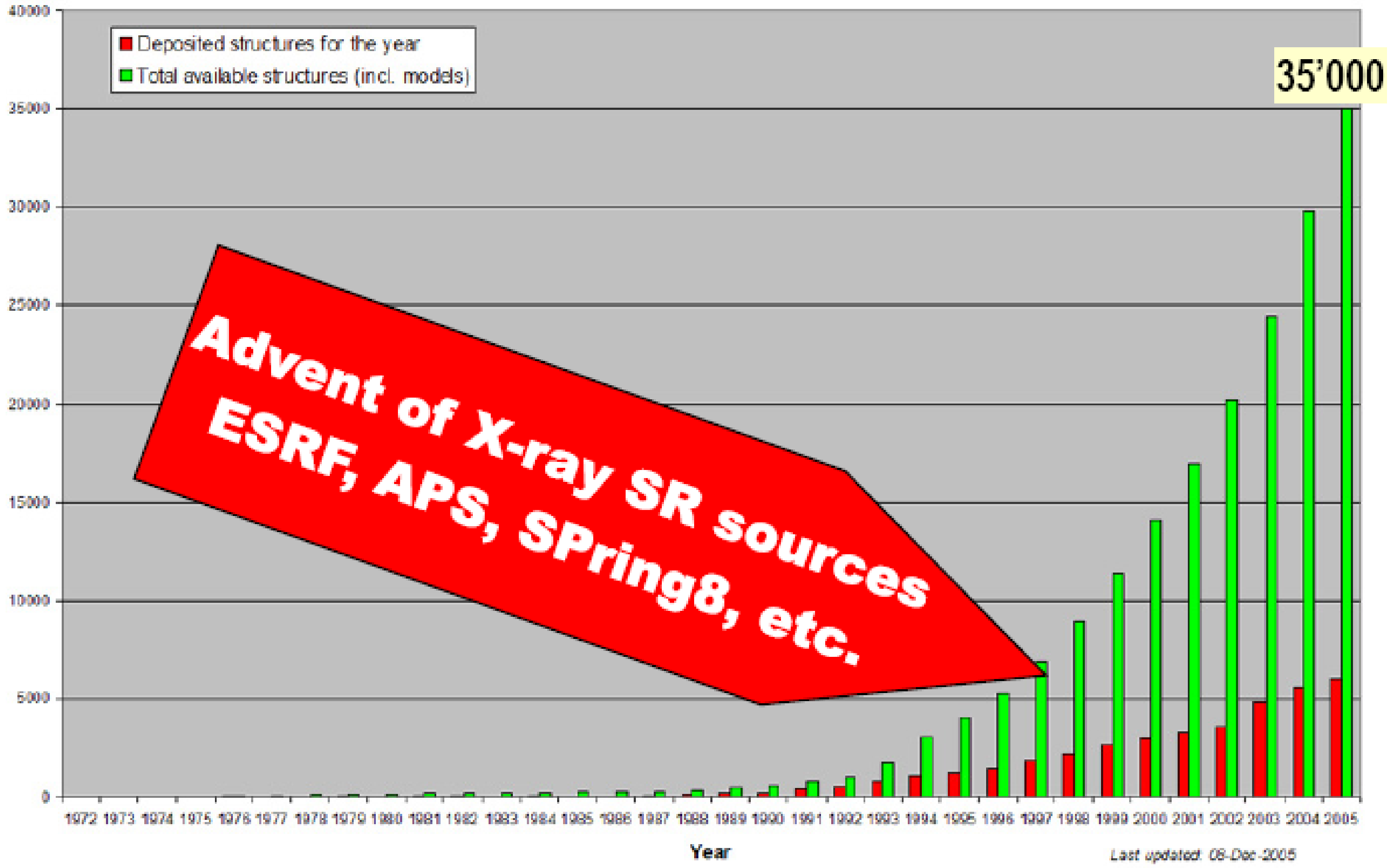


3411 unique users in 2007



2006 Protein Data Bank deposits

Spectacular growth of structural biology



X-ray sources, ICFA Seminar, SNAL, October 2008, L. Rivkin, PSI & EPFL

Outline

1. Introduction
   - AOFSRR / Cheiron School
   - History of SR
   - SR

2. 1^{st}-2^{nd} Generation SR

3. 3^{rd} Generation SR
   - Current Status of 3^{rd} Generation SR Facilities
   - Applications in Science &Technology

4. 4^{th} Generation SR
   - Current Status of 4^{th} Generation SR Facilities
   - Applications in Science &Technology

5. Summary & Conclusions

Scientific Demands

Coherency

Atomic and nanoscale imaging (Cells & Viruses, Nano-materials etc.), Others

Femto-second science

Real-time reaction with high repetition rate
(Chemical reaction, Photo-induced phase transition etc.)

Nano beam

Condensed matter physics under extreme conditions

Performances

Brilliance : brighter by 2 orders

Pulse width : shorter by 2 orders

compared to those of 3rd generation SR

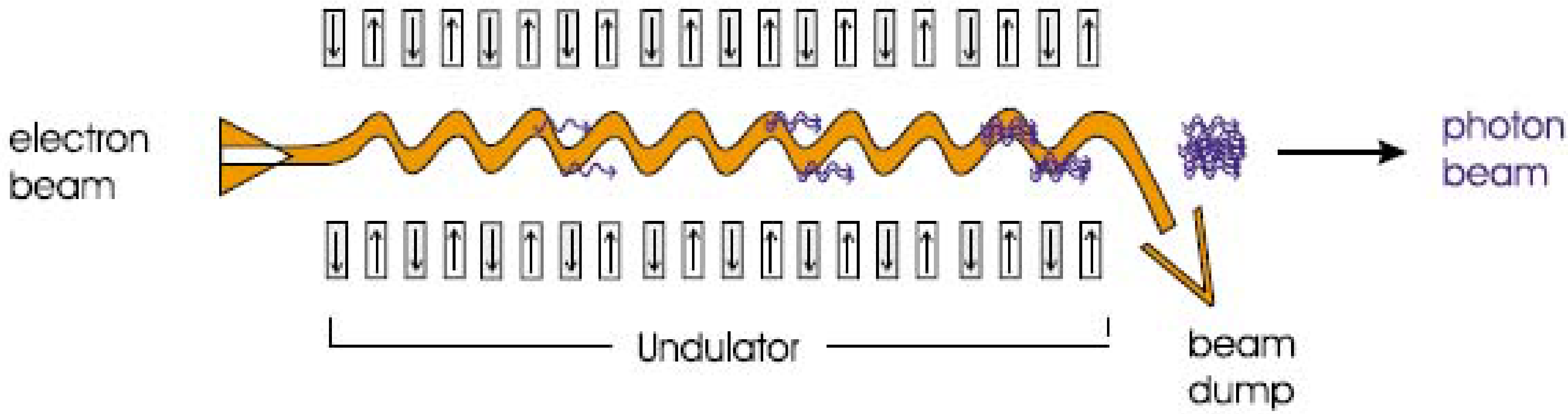
New Light Source

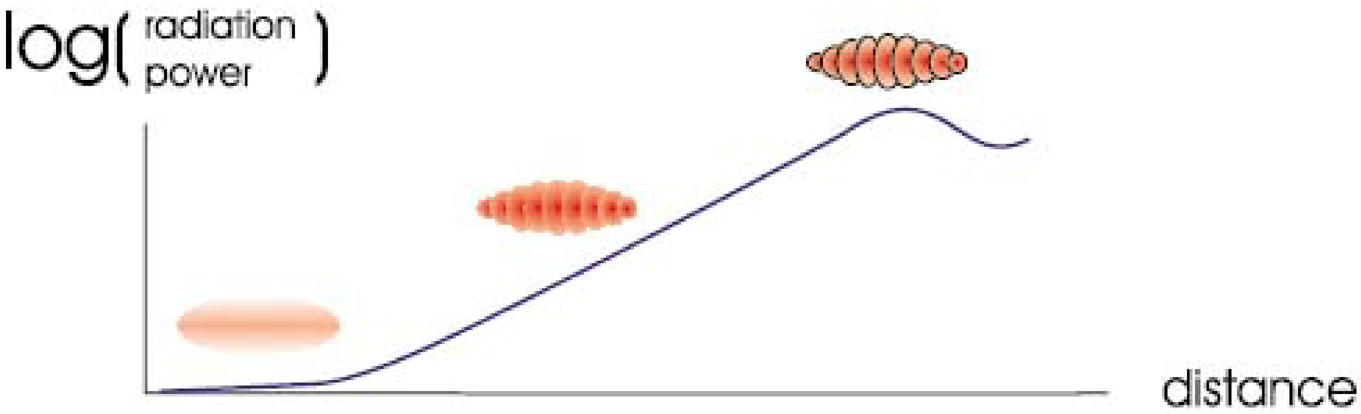
- X-Ray Free Electron Laser (XFEL)
- Energy Recovery Linear-Accelerator (ERL)

4th Generation SR

X-Ray Free Electron Laser (XFEL)

Self Amplification of Spontaneous Emission (SASE)

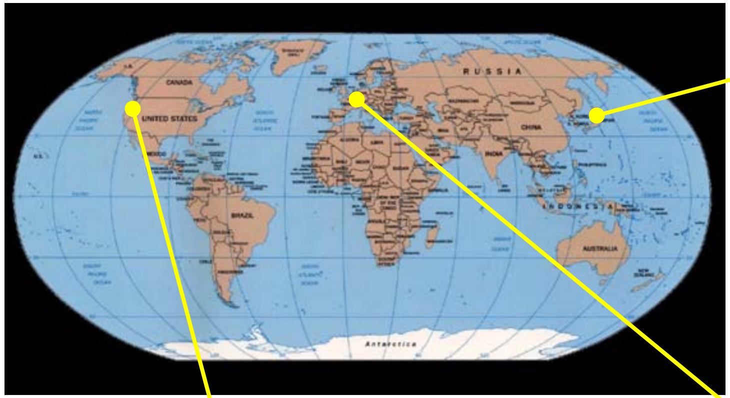




XFELs around the World

Project	Type	Location	Country	e-Beam (GeV)	Photon (nm)	Status
LEUTL	SASE	APS	USA	0.22	660-130	Since 2001
TTF I	SASE	DESY	Germany	0.3	125-85	Since 2002
SDL DUV-FEL	HGHG	SDL/NSLS	USA	0.145	400-100	Since 2002
FLASH (TTF)	SASE	DESY	Germany	1.0	12 - 6	Since 2006
SCSS Prototype	SASE	SPring-8	Japan	0.25	150-50	Since 2006
LCLS	SASE	SLAC	USA	14.5	0.15	in 2009
SACLA	SASE	SPring-8	Japan	8	0.1 (0.05)	in 2011
Euro XFEL	SASE	DESY	Germany	17.5	0.05	in 2014
PAL XFEL	SASE	Pohang	Korea	10	0.06	in 2014
PSI XFEL	SASE	PSI	Swiss	5.8	0.1	(in 2016)
SPARC	SASE	INFN Frascati	Italy	0.15	500	in 2007
FERMI	HGHG	Trieste	Italy	1.2	10	in 2011
DUV/Soft X-ray	HGHG	SINAP	China	0.8-1.3	>3	approved
Soft X-ray FEL	HGHG	BESSY	Germany	2.3	64 - 1.2	proposal
SPARX	HHG	INFN Frascati	Italy	1 - 2	1.5	proposal
4GLS	HGHG	Daresbury	GB	0.6	100 - 19	proposal
ARC-EN CIEL	HHG	Saclay	France	0.7	1	proposal

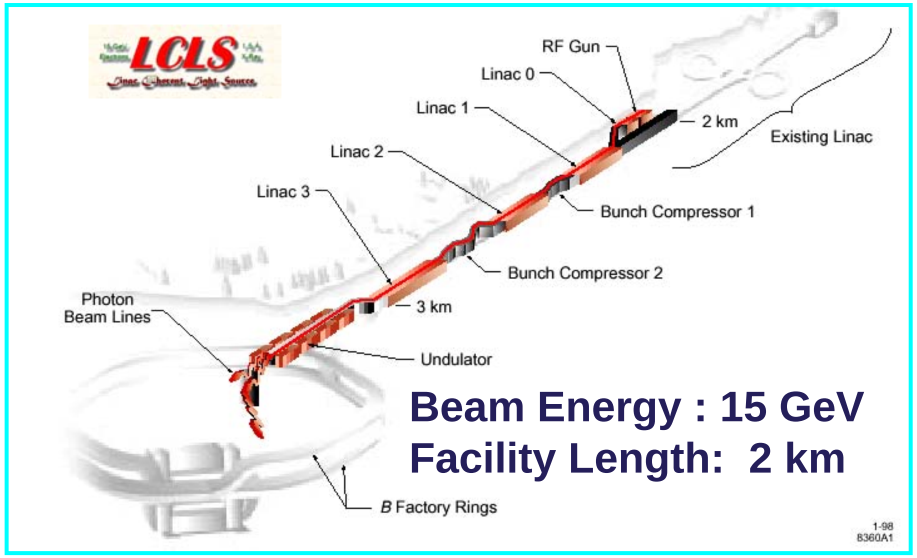
Leading XFEL Facilities



SP8-XFEL
SPring-8
2010

Beam Energy : 8 GeV
Facility Length : 0.7 km, 390 M$

LCLS, Stanford, 2009
(First XFEL demonstration on April 10, 2009)



Beam Energy : 15 GeV
Facility Length: 2 km

E-XFEL, Hamburg, DESY, 2014

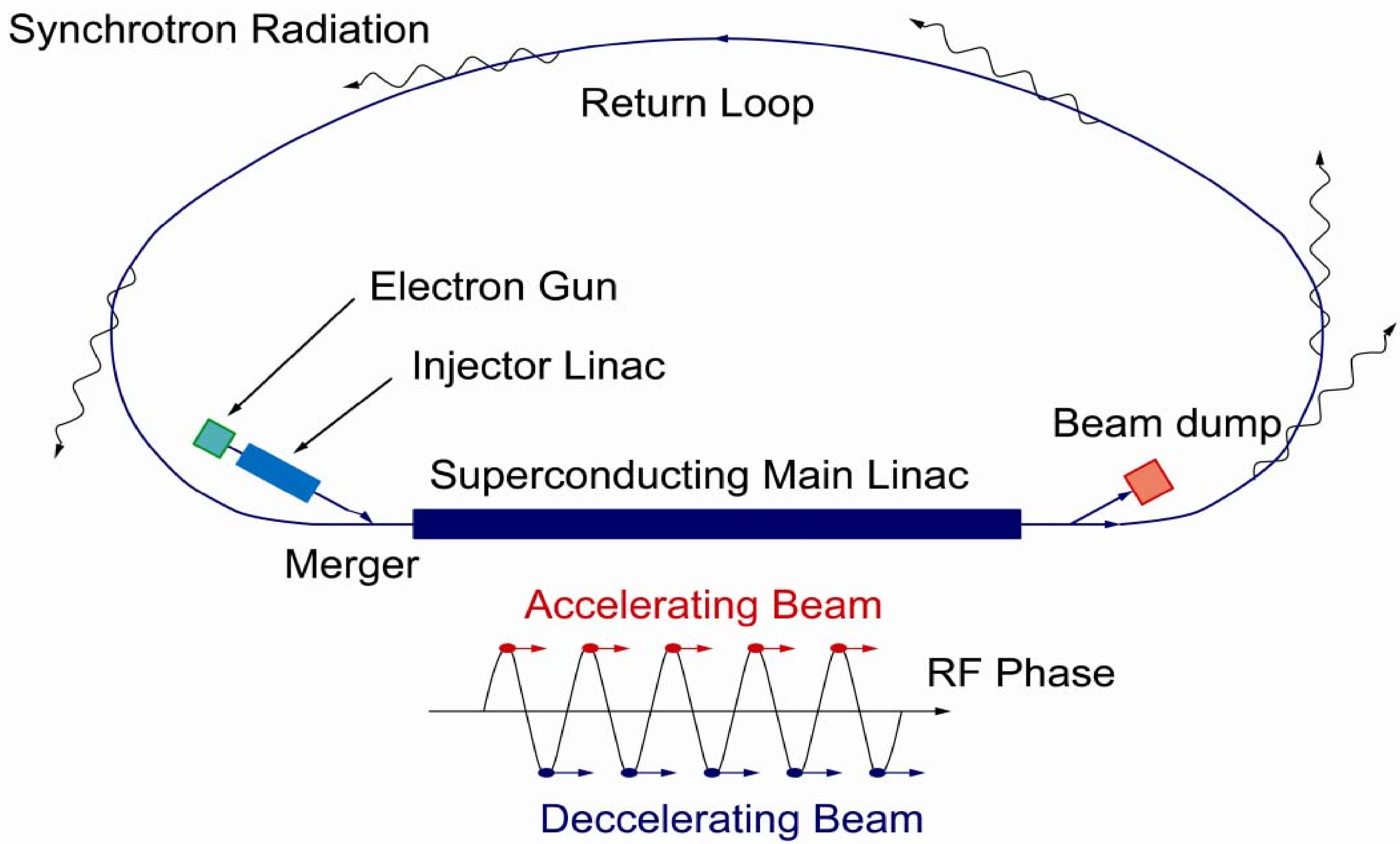
Beam Energy : 20 GeV
Facility Length : 3 km, 1500 M$

Korea

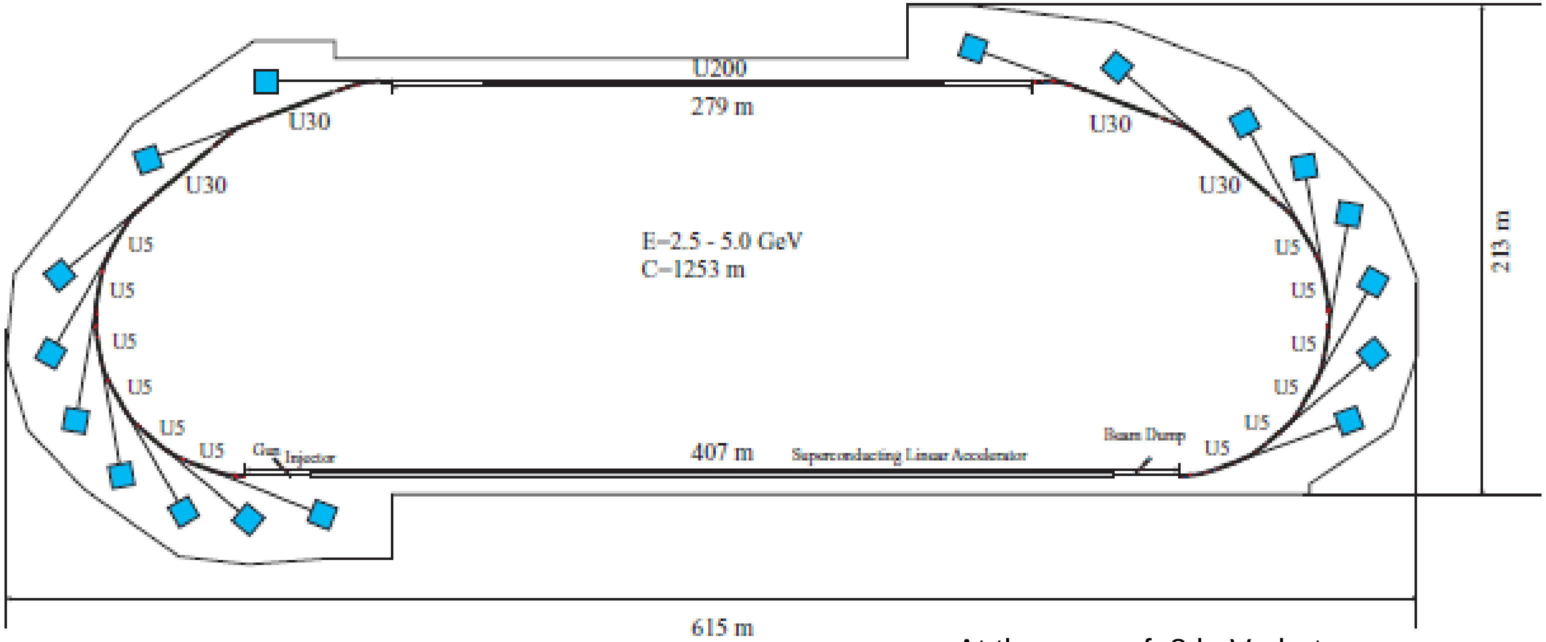
Pohang
PLS-II
DBA, 3 GeV, 5.8nm.rad, 20 ID BLs
PAL-XFEL
▪Linac Energy : 10 GeV
▪X-ray Wavelength : 0.06 nm
▪Project Period : 2011 ~ 2014


PAL-XFEL
금속패널
복층유리
금속지붕재
PAL 포항가속기연구소

Energy Recovery Linac (ERL)



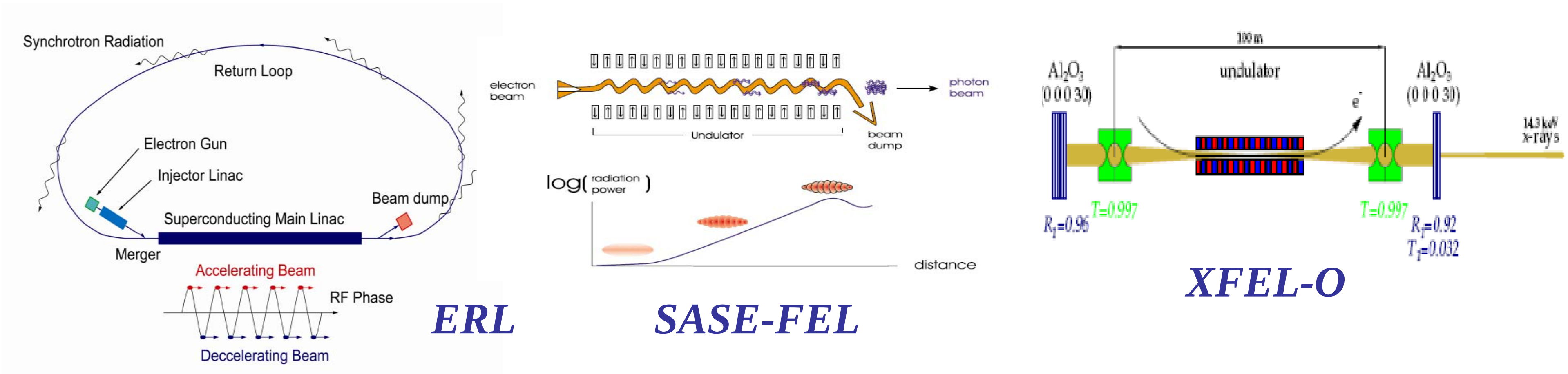
PF(KEK) - ERL



At the case of 8 keV photon energy

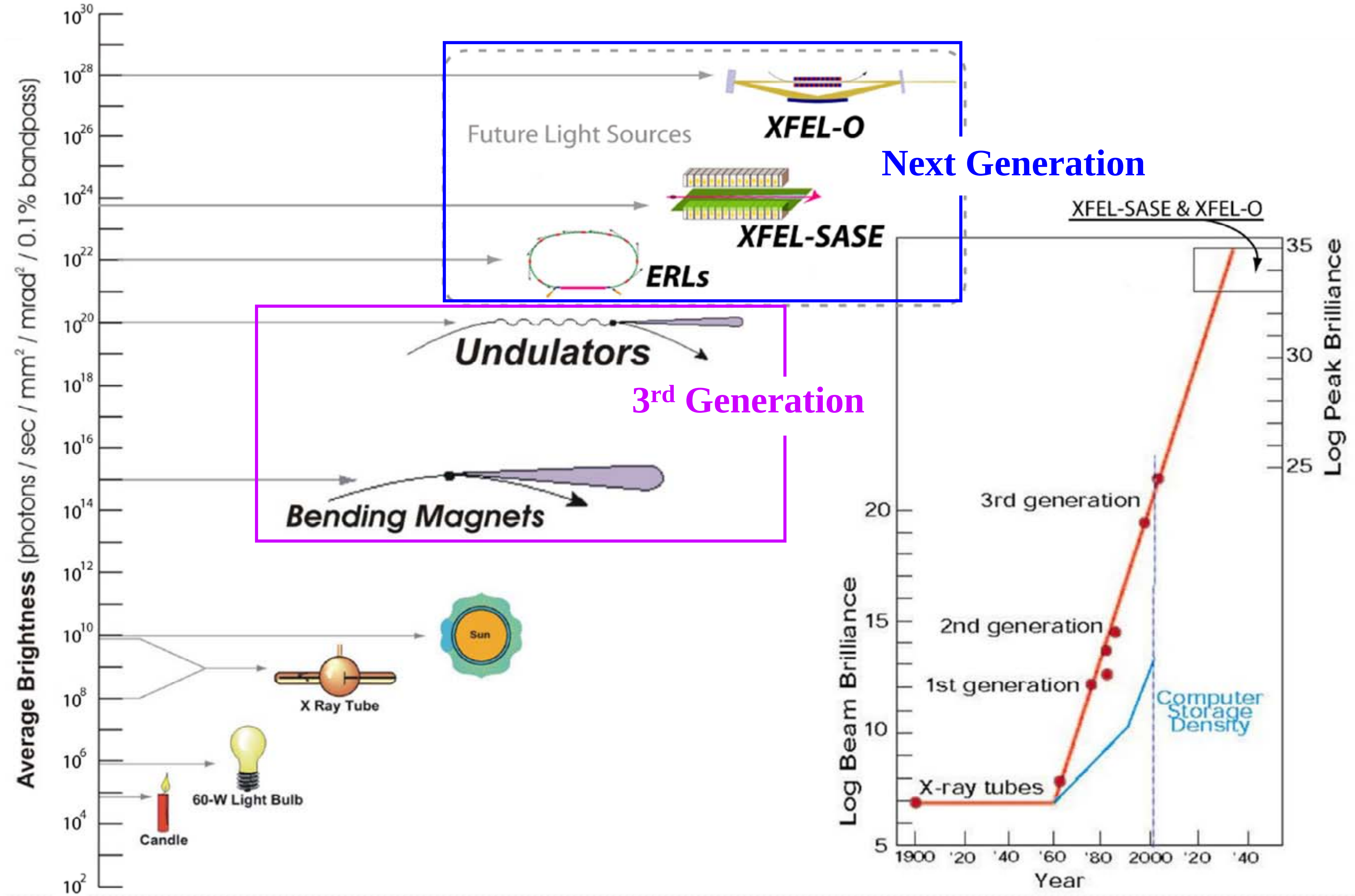
		PF-ERL undulator @ 5 GeV		SPring-8 undulator @ 8 GeV	
Beam current		100 mA	100 mA	100 mA	100 mA
Undulator length		30 m	5 m	25 m	5 m
Source size (μm)	horizontal	37.8	18.2	892	892
	vertical	37.8	18.2	22.8	10.6
Source div. (μrad)	horizontal	4.1	9.8	37.4	38.4
	vertical	4.1	9.8	4.3	10
Beam size @ 50 m (μm)	horizontal	244	510	2761	2813
	vertical	244	510	236	509
Average brilliance(ph/s/0.1%/mm^2/mr^2)		6.0×10^{23}	7.6×10^{22}	2.2×10^{21}	5.0×10^{20}
% beam coherence		19	15	0.14	0.13

Functions of XFEL(SASE), XFEL-O & ERL



SR	average brilliance	peak brilliance	repetition rate (Hz)	coherent fraction	bunch width(ps)	# of BLs	Remark
XFEL (SASE)	$\sim10^{22\sim24}$	$\sim10^{33}$	100~10K	100%	0.1	few	One-shot measurement
XFEL-O (Option)	$\sim10^{27}$	$\sim10^{33}$	~1M	100%	1	few	Single mode FEL
ERL	$\sim10^{23}$	$\sim10^{26}$	1.3G	~20%	0.1~1	~30	Non-perturbed measurement
3rd-SR	$\sim10^{20\sim21}$	$\sim10^{22}$	~500M	0.1%	10~100	~30	Non-perturbed measurement

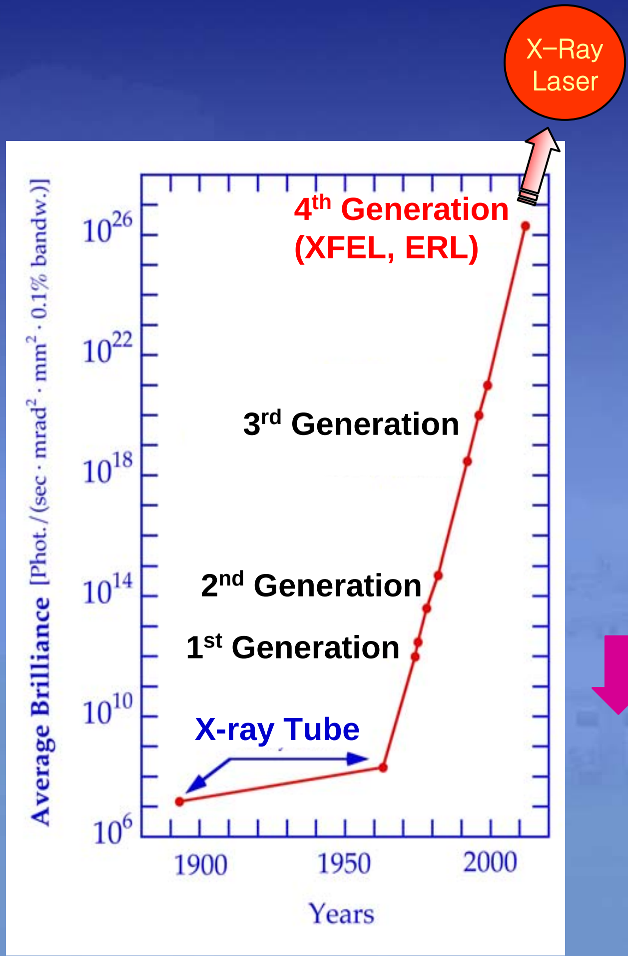
(brilliance : photons/mm^2/mrad^2/0.1%/s @ 10 keV)


Average Brightness (photons / sec / mm² / mrad² / 0.1% bandpass)
10^30
10^28
10^26
10^24
10^22
10^20
10^18
10^16
10^14
10^12
10^10
10^8
10^6
10^4
10^2
Future Light Sources
XFEL-O
Next Generation
XFEL-SASE
ERLs
Undulators
3rd Generation
Bending Magnets
Sun
X Ray Tube
60-W Light Bulb
Candle
XFEL-SASE & XFEL-O
Log Peak Brilliance
35
30
25
Log Beam Brilliance
20
15
10
5
3rd generation
2nd generation
1st generation
X-ray tubes
Computer Storage Density
1900 '20 '40 '60 '80 2000 '20 '40
Year

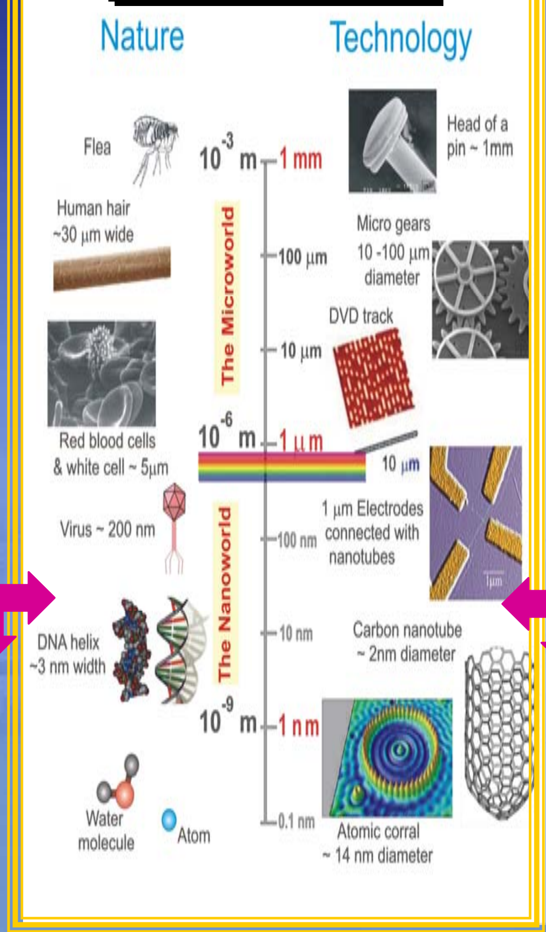
Applications of XFEL in Science

XFEL
ERL

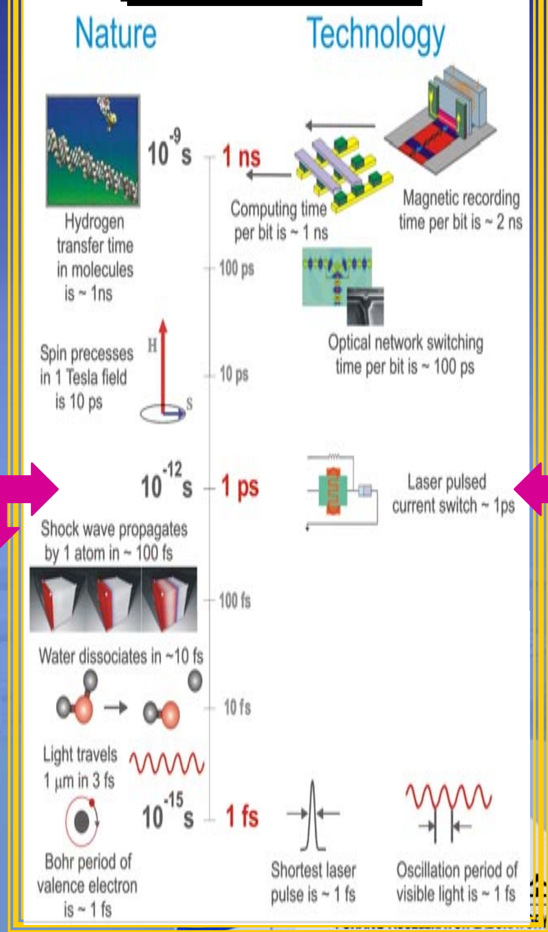
- Coherent beam source
- Higher flux beam source
- Smaller size beam source
- Pulse beam source (~ fs)



Ultra-small



Ultra-fast



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    - Current Status of 4th Generation SR Facilities
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5. **Summary & Conclusions**

Summary and Conclusions

- The development of third generation light source is still active and growing. There will be about 8 new ones operational before 2015.
- Intermediate energy light sources, such as Diamond, SOLEIL, ASP, Indus-2, ALBA, SSRF, CANDLE, NSLS-II, TPS, MAX-IV have been the focus of the recent development, the cost-effective feature makes them very suitable for meeting regional scientific needs of doing cutting-edge studies in various fields.
- Future development is very promising, not only the high energy physics machines will be converted to advanced light sources, like PRTRA-III and PEP-X, but also the ultimate storage ring light source is also very competitive.
- Two 4th generation facilities (XFEL) are in operation and more facilities are coming soon, and thus one may expect unforeseen results. ERL and XFELO are other new approaches in competing with the 4th generation machines
- Users are very much diversified and expanding rapidly to other research areas

M. Ree’s Group (POSTECH)

1. Research Fields

<Polymer Physics>

- Nanostructures and Morphology
- 3D Single Molecule Structure
- Polymer Chain Conformation
- Surface, Interfaces
- Electric, dielectric, optical, thermal, mechanical properties
- Sensor properties

<Polymer Synthesis>

- Functional polymers
- Structural polymers
- Polypeptides, DNA, RNA

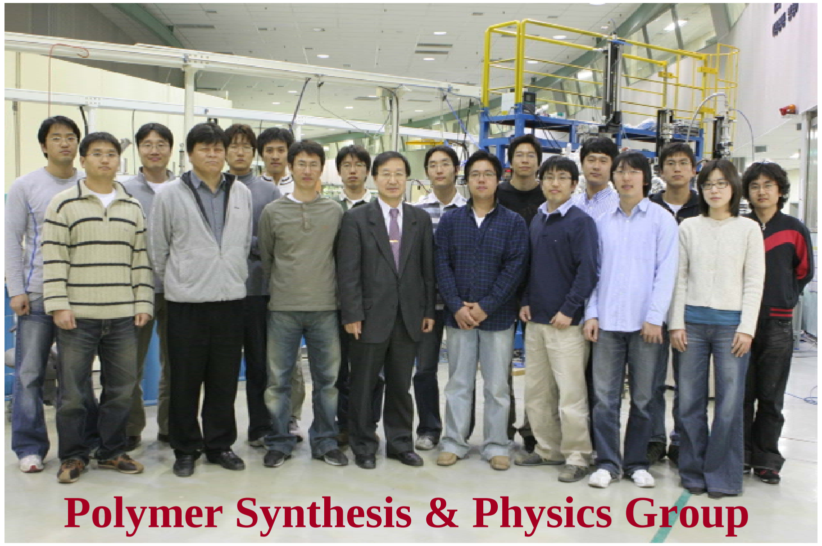
http://www.postech.ac.kr/chem/mree

Scattering / Reflectivity:
Synchrotron X-Ray, Neutron, Lasers

- ♦ Polymers for Microelectronics, Displays, & Sensors
- ♦ Polymers for Implants & Biological Systems
- ♦ Proteins & Polynucleic acids (DNA, RNA)

2. Group Members

15 Ph.D. candidates
2 Postdoctors
2 Technicians
4 Scientists (PLS: Coworkers)



Polymer Synthesis & Physics Group


Spring-8
Korea


Kimpo International Airport
Seoul
Seoul Station
Express bus Station
Pohang
Pusan
Kimhae International Airport
Cheju Island


Korea
Seoul
Daejeon
Pohang
Daegu
Gwangju
Busan


Pohang Light Source
POSTECH
Campus

Thank you very much for your attention !!!