Progetti FEL e Light Sources world-wide

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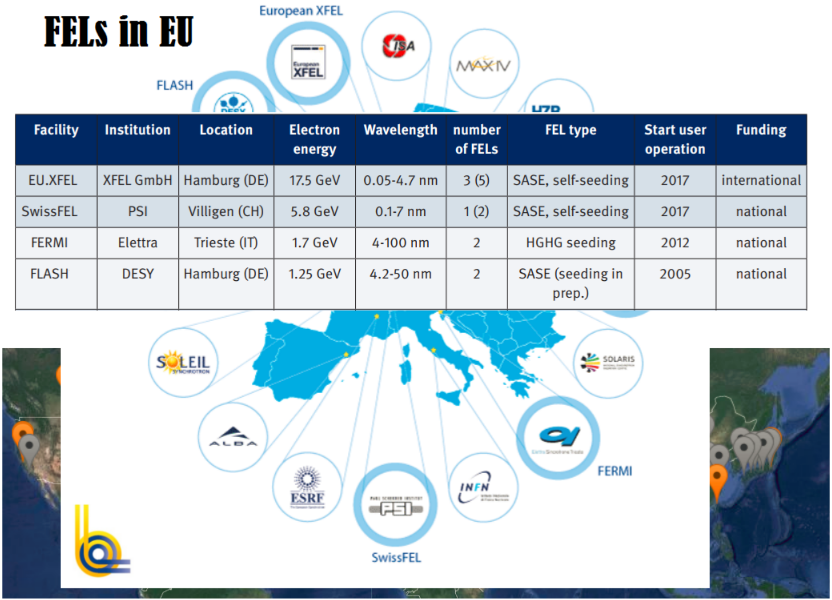
Light sources nel mondo

FELs in Europa

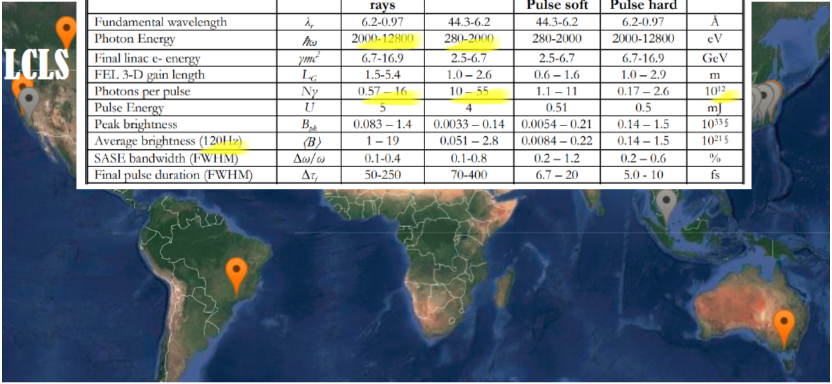
FELs in Europa



Facility	Institution	Location	Electron energy	Wavelength	number of FELs	FEL type	Start user operation	Funding
EU.XFEL	XFEL GmbH	Hamburg (DE)	17.5 GeV	0.05-4.7 nm	3 (5)	SASE, self-seeding	2017	international
SwissFEL	PSI	Villigen (CH)	5.8 GeV	0.1-7 nm	1 (2)	SASE, self-seeding	2017	national
FERMI	Elettra	Trieste (IT)	1.7 GeV	4-100 nm	2	HGHG seeding	2012	national
FLASH	DESY	Hamburg (DE)	1.25 GeV	4.2-50 nm	2	SASE (seeding in prep.)	2005	national

XFELs nel mondo

LCLS @ SLAC (operativo dal 2009)



LCLS general SASE parameters

Photon Beam Parameters	Symbol	Hard x-rays	Soft x-rays	Short Pulse soft	Short Pulse hard	Unit
Fundamental wavelength	λ_r	6.2-0.97	44.3-6.2	44.3-6.2	6.2-0.97	Å
Photon Energy	$\hbar\omega$	2000-12800	280-2000	280-2000	2000-12800	eV
Final linac e- energy	γmc^2	6.7-16.9	2.5-6.7	2.5-6.7	6.7-16.9	GeV
FEL 3-D gain length	L_G	1.5-5.4	1.0 – 2.6	0.6 – 1.6	1.0 – 2.9	m
Photons per pulse	$N\gamma$	0.57 – 16	10 – 55	1.1 – 11	0.17 – 2.6	10^{12}
Pulse Energy	U	5	4	0.51	0.5	mJ
Peak brightness	B_{pk}	0.083 – 1.4	0.0033 – 0.14	0.0054 – 0.21	0.14 – 1.5	10^{33} §
Average brightness (120Hz)	$\langle B \rangle$	1 – 19	0.051 – 2.8	0.0084 – 0.22	0.14 – 1.5	10^{21} §
SASE bandwidth (FWHM)	$\Delta\omega/\omega$	0.1-0.4	0.1-0.8	0.2 – 1.2	0.2 – 0.6	%
Final pulse duration (FWHM)	$\Delta\tau_r$	50-250	70-400	6.7 – 20	5.0 - 10	fs

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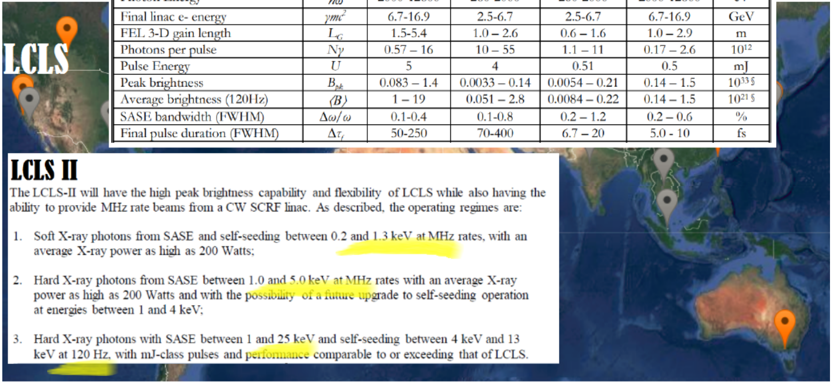

LCLS II

The LCLS-II will have the high peak brightness capability and flexibility of LCLS while also having the ability to provide MHz rate beams from a CW SCRF linac. As described, the operating regimes are:

1. Soft X-ray photons from SASE and self-seeding between 0.2 and 1.3 keV at MHz rates, with an average X-ray power as high as 200 Watts;

2. Hard X-ray photons from SASE between 1.0 and 5.0 keV at MHz rates with an average X-ray power as high as 200 Watts and with the possibility of a future upgrade to self-seeding operation at energies between 1 and 4 keV;

3. Hard X-ray photons with SASE between 1 and 25 keV and self-seeding between 4 keV and 13 keV at 120 Hz, with mJ-class pulses and performance comparable to or exceeding that of LCLS.

LCLS @ SLAC (operativo dal 2009)

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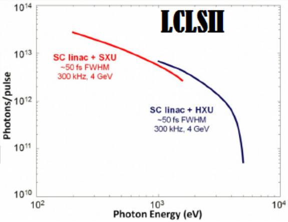
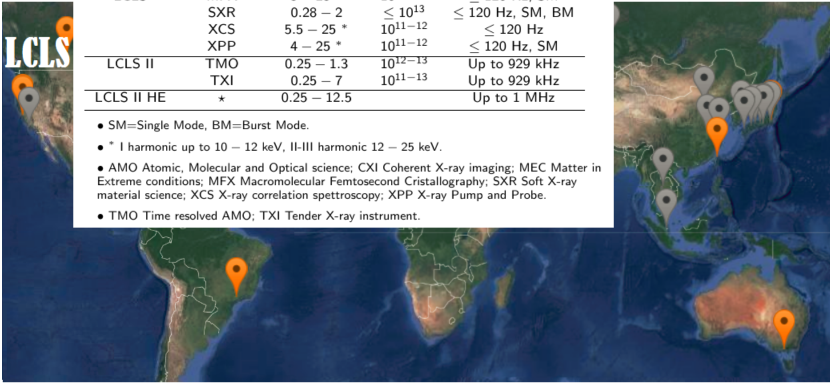
2. Hard X-ray photons from SASE between 1.0 and 5.0 keV at MHz rates with an average X-ray power as high as 200 Watts and with the possibility of a future upgrade to self-seeding operation at energies between 1 and 4 keV;
3. Hard X-ray photons with SASE between 1 and 25 keV and self-seeding between 4 keV and 13 keV at 120 Hz, with mJ-class pulses and performance comparable to or exceeding that of LCLS.



LCLS @ SLAC (operativo dal 2009)



Facility	Application	Ph En (keV)	Ph/pulse	Rep rate
LCLS	AMO	0.48 – 2	$\leq 10^{13}$	$\leq$ 120 Hz
	CXI	5 – 25	10^{11-12}	$\leq$ 120 Hz, SM
	MEC	2.5 – 25 *	10^{11-12}	$\leq$ 120 Hz
	MFX	5 – 25 *	10^{11-12}	$\leq$ 120 Hz, SM
	SXR	0.28 – 2	$\leq 10^{13}$	$\leq$ 120 Hz, SM, BM
	XCS	5.5 – 25 *	10^{11-12}	$\leq$ 120 Hz
	XPP	4 – 25 *	10^{11-12}	$\leq$ 120 Hz, SM
LCLS II	TMO	0.25 – 1.3	10^{12-13}	Up to 929 kHz
	TXI	0.25 – 7	10^{11-13}	Up to 929 kHz
LCLS II HE	$\star$	0.25 – 12.5		Up to 1 MHz

- SM=Single Mode, BM=Burst Mode.
- * I harmonic up to 10 – 12 keV, II-III harmonic 12 – 25 keV.
- AMO Atomic, Molecular and Optical science; CXI Coherent X-ray imaging; MEC Matter in Extreme conditions; MFX Macromolecular Femtosecond Cristallography; SXR Soft X-ray material science; XCS X-ray correlation spettroscopy; XPP X-ray Pump and Probe.
- TMO Time resolved AMO; TXI Tender X-ray instrument.

LCLS @ SLAC (operativo dal 2009)

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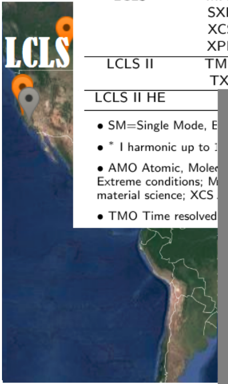
LCLS II HE				

- SM=Single Mode, E
- * I harmonic up to 1
- AMO Atomic, Molec
Extreme conditions; M
material science; XCS
- TMO Time resolved



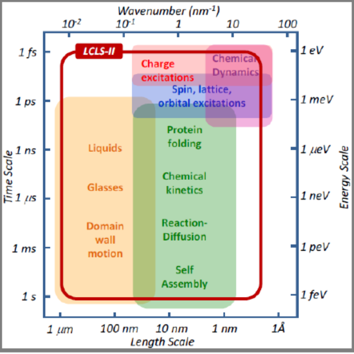


Figure 49. Time and length scales of spontaneous dynamics associate with various materials and chemical processes. X-ray photon correlation spectroscopy operates in a key area not accessible by other techniques. LCLS-II will open up new frontiers in correlation spectroscopy by characterizing materials over a broad range of length and time scales. Note that time resolution scales as the square of the average brightness, and LCLS-II will be ~1,000 brighter than any soft X-ray storage ring.

LCLS @ SLAC (operativo dal 2009)

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	CXI	5 – 25
	MEC	2.5 – 25 *
	MFX	5 – 25 *
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	XPP	4 – 25 *
LCLS II	TMO	0.25 – 1.3
	TXI	0.25 – 7
LCLS II HE	⋆	0.25 – 12.5

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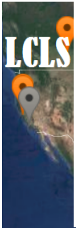

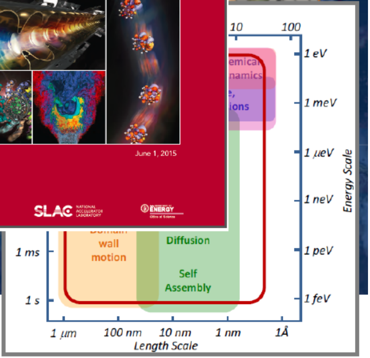

https://portal.slac.stanford.edu/sites/lcls_public/Documents/LCLS-IIScienceOpportunities_final.pdf

LCLS @ SLAC (operativo dal 2009)

Facility	Application	Ph En (keV)	Ph/pulse	Rep rate
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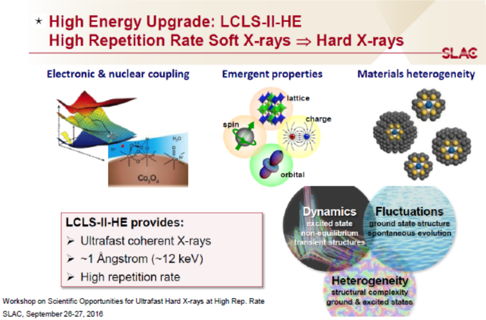
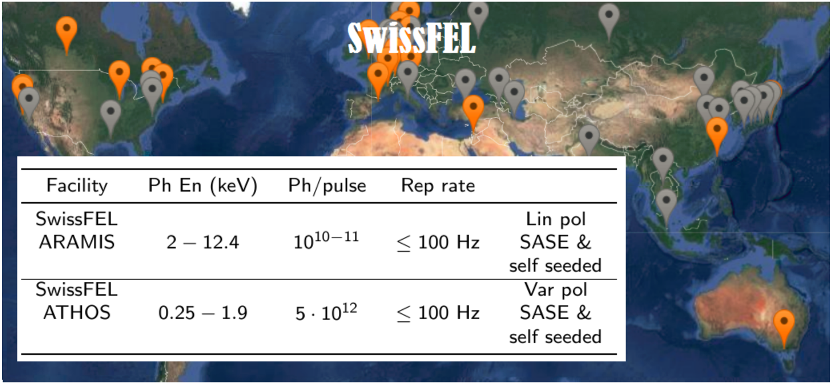
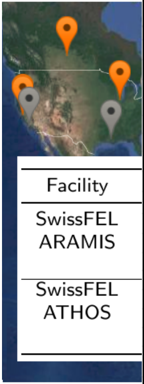


SwissFEL @ PSI (operativo dal 2017)



Facility	Ph En (keV)	Ph/pulse	Rep rate	
SwissFEL ARAMIS	2 – 12.4	10^{10-11}	$\leq$ 100 Hz	Lin pol SASE & self seeded
SwissFEL ATHOS	0.25 – 1.9	$5 \cdot 10^{12}$	$\leq$ 100 Hz	Var pol SASE & self seeded

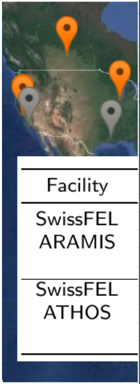
SwissFEL @ PSI (operativo dal 2017)

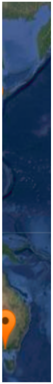


ARAMIS

Experiment type	System	ΔE / E	Photons / Pulse	Timescale (Pulse length)	Other
1 – Coherent diffraction					
1.1 - Nanostructures (on surfaces or in injected droplets)					
Lensless imaging, ptychography	2D biocrystals	0.1 %	10^{11}	< 20 fs	0.1-1 µm spot
Coherent diffraction	Protein nanocrystals	0.1 %	10^{11}	< 100 fs (?)	
Cross-correlation scattering	Soft disordered matter	0.1 %	10^{11}	< 50 fs	
Single molecule diffraction	Proteins in aerosol jet	0.1 %	$> 10^{11}$	< 20 fs	100 nm spot
2 – Pump-Probe					
2.1 – Single-shot spectroscopy (on surfaces or in liquid jets)					
Pump: THz, IR, vis., Probe: XES / XANES	Chem. / Biochem. systems	1 %	10^{11}	60 fs	E dispersive det.
2.2 – Diffraction / Scattering					
Pump: vis., Probe: SAXS	Solution chemistry	0.1 %	$> 10^{11}$	10 fs	Liquid jet
Pump: IR, vis., Probe: Bragg	Coherent phonons	0.1-1%	10^{10}	6-30 fs (Q = 20 pC)	Diffractometer
Pump: vis., Probe: Laue	Photo-excited proteins	1%	$> 10^{11}$	> 100 fs	
Pump: X-ray, Probe: X-ray (XPCS)	Interlayer diffusion	0.1%	10^{11}	50 fs	Split-delay < 2 ns
3 – Other					
3.1 – Mössbauer techniques (14.4 keV ± 10^{-8} eV)					
Slow fluctuations (100 ns), Photon echos, Inelastic scattering	Various	$2 \cdot 10^{-12}$	$> 10^{11}$	> 100 fs	Pre-monoch.
3.2 – Ion implantation					
Pump: Ion implantation Probe: diffuse scattering / diffraction	Reactor steel	0.1 %	10^{11}	100 fs	Synchronized ion implantation device

SwissFEL @ PSI (operativo dal 2017)

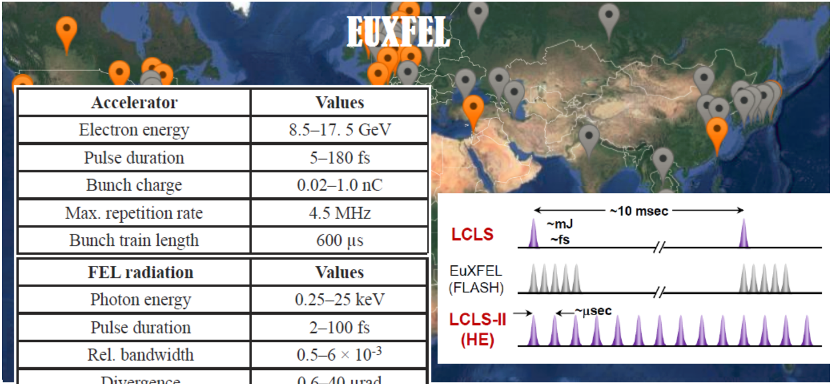




ATHOS

Experiment type	System	Δ E / E	Δ E step (< 5 s)	Photons / Pulse	Timescale (Pul. length)	Pol.	Other
3 – Pump-probe Imaging and Scattering							
3.1 – External pumping (THz, IR, vis.)							
Resonant diffraction	Perovskites (3d-ions, oxygen)	0.01 %	0.1 eV	$5 \cdot 10^{12}$	10 fs	Var.lin.	Diffractometer
Holography	Magnetic thin films	0.1 %	1 eV	$5 \cdot 10^{12}$	100 fs	Circ.	
3.2 – X-ray pumping							
XPCS (delay < 10 ps)	Corr. el.	0.1 %	---	$5 \cdot 10^{12}$	10 fs	Lin.	Split-delay line
Cross corr. scattering	Magnetic fluctuations	0.1 %	1 eV	$5 \cdot 10^{12}$	10 fs	Lin.	
2 – Pump-Probe spectroscopy							
2.1 – Monochromatic (pump: THz, IR, vis.)							
XANES, XES	Catalysis and Biochemistry	0.01 %	0.1 eV	$5 \cdot 10^{12}$	60 fs	Lin.	μ-liquid jet
XMCD	Magnetism and Corr. el. syst.	0.1 %	1 eV	$5 \cdot 10^{12}$	10 fs	Circ.	
(spin-resolved) PE spect	Magnetism and Corr. el. syst.	0.1 %	1 eV	10^7@1kHz	10 fs	Lin.	TOF PE detector
2.2 – Single-shot broadband (pump: THz, IR, vis.)							
XANES, XES	Catalysis and Biochemistry	1 %	10 eV	$5 \cdot 10^{12}$	60 fs	Lin.	No mono / seeding
XMCD	Magnetism and Corr. el. syst.	1 %	10 eV	$5 \cdot 10^{12}$	10 fs	Circ.	No mono / seeding
1 – Inelastic scattering							
1.1 Pump-Probe energy dispersive RIXS							
Single-shot RIXS	Molecules and Corr. el.	1 %	1 eV	$> 5 \cdot 10^{12}$	10 fs	Var. lin.	Strocov det. no seed
1.2 Time-domain heterodyne spectroscopy							
FROG	Molecules and Corr. el.	0.1 %	---	$5 \cdot 10^{12}$	10 fs	Lin.	Seeded pulses

European XFEL (operativo dal 2017)



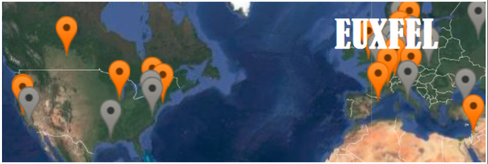
Accelerator	Values
Electron energy	8.5–17. 5 GeV
Pulse duration	5–180 fs
Bunch charge	0.02–1.0 nC
Max. repetition rate	4.5 MHz
Bunch train length	600 µs

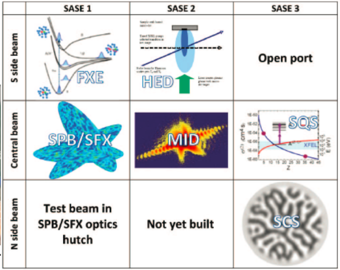
FEL radiation	Values
Photon energy	0.25–25 keV
Pulse duration	2–100 fs
Rel. bandwidth	0.5–6 × 10^{-3}
Divergence	0.6–40 µrad
Pulse energy at 1 nC	0.5–10 mJ

European XFEL (operativo dal 2017)

Starting User Operation at the European XFEL

T. Tschentscher and R. Feidenhans'l
(on behalf of the staff at European XFEL and in the institutes collaborating on the construction of the accelerator and photon beam systems)
European XFEL, Schenefeld, Germany

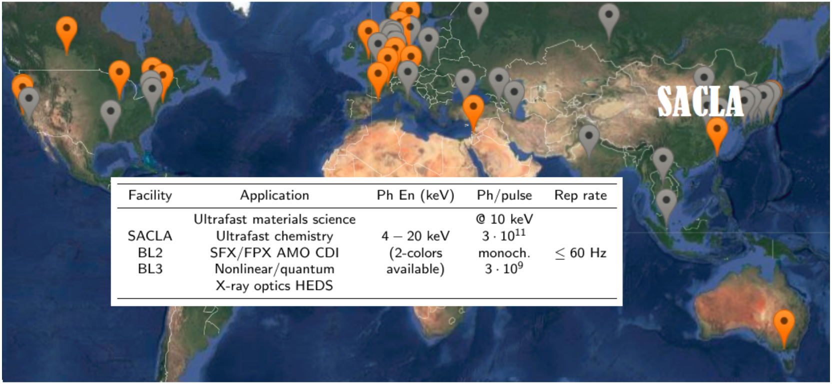




Facility		Application	Ph En (keV)
XFEL	SASE1	SPB/SFX, FXE	3 – 25
	SASE2	MID, HED	3 – 25
	SASE3	SQS, SCS	0.26 – 3

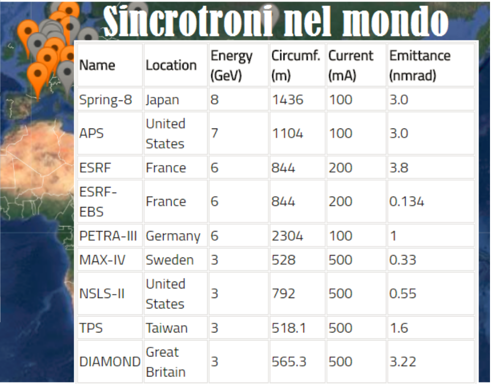
- SPB/SFX Ultrafast coherent diffraction imaging of single particles, clusters and biomolecules; FXE Femtosecond X-ray experiments: time-resolved investigations of dynamics of solids, liquids, gases; MID Materials imaging & dynamics at the nanoscale; HED High energy density matter (hard X-ray, e.g. probing dense plasmas); SQS Small quantum systems: investigation of atoms, ions, molecules and clusters in intense fields and non-linear phenomena; SCS Spectroscopy & coherent scattering: Electronic and atomic structure and dynamics of nanosystems and of non-reproducible biological objects (soft X-rays);

SACLA @ RIKEN/HARIMA (operativo dal 2011)



Facility	Application	Ph En (keV)	Ph/pulse	Rep rate
SACLA BL2 BL3	Ultrafast materials science Ultrafast chemistry SFX/FPX AMO CDI Nonlinear/quantum X-ray optics HEDS	$4 - 20$ keV (2-colors available)	@ 10 keV $3 \cdot 10^{11}$ monoch. $3 \cdot 10^{9}$	≤ 60 Hz

Sincrotroni in Europa e nel mondo



Name	Location	Energy (GeV)	Circumf. (m)	Current (mA)	Emittance (nmrad)
Spring-8	Japan	8	1436	100	3.0
APS	United States	7	1104	100	3.0
ESRF	France	6	844	200	3.8
ESRF-EBS	France	6	844	200	0.134
PETRA-III	Germany	6	2304	100	1
MAX-IV	Sweden	3	528	500	0.33
NSLS-II	United States	3	792	500	0.55
TPS	Taiwan	3	518.1	500	1.6
DIAMOND	Great Britain	3	565.3	500	3.22
ALBA	Spain	3	268.8	200	4.33
SSRF	China	3	431.84	500	2.61
ASP	Australia	3	216.28	500	7.12
SIRIUS	Brazil	3	518.4	500	0.25
SOLEIL	France	2.75	354	500	3.68

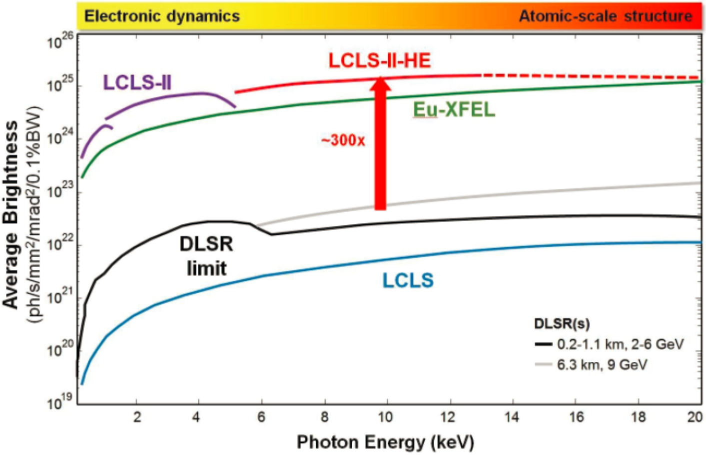
ESRF (operativo dal 1991)

Alcune linee di fascio

Facility	Scientific Application	Photon Energy
ESRF ID12	XAS XMCD XMLD XNCD XMchiD XDMR XNLD XNLD	2.05 – 15 keV
ESRF ID21	XANES XRF MicroXRF MicroXANES XRD	2.1 – 9.2 keV
ESRF ID32	XMCD XMLD XAS XES IXS XANES XRS	0.3 – 1.6 keV
ESRF ID29	SAXS BioSAXS	7 – 15 keV
ESRF ID30A	Investigation of Proteins	7 – 18 keV

XAS X-ray absorption spectroscopy; XMCD X-ray magnetic circular dichroism;
XMLD X-ray magnetic linear dichroism; XNCD X-ray natural circular dichroism;
XMchiD X-ray magnetochiral dichroism; XDMR X-ray detected magnetic resonance;
XNLD X-ray natural linear dichroism; XNLD X-ray natural linear dichroism;
XANES X-ray absorption near-edge structure; XRF X-ray fluorescence;
MicroXRF micro X-ray fluorescence; MicroXANES micro X-ray absorption near-edge structure;
XRD X-ray diffraction; XMCD X-ray magnetic circular dichroism;
XMLD X-ray magnetic linear dichroism; XAS X-ray absorption spectroscopy;
XES X-ray emission spectroscopy; IXS inelastic X-ray scattering;
XANES X-ray absorption near-edge structure; XRS X-ray Raman scattering;
SAXS small-angle X-ray scattering; BioSAXS small-angle X-ray scattering (proteins/DNA)

Energie-Brillanza



The Linac Coherent Light Source: Current Status and Future Direction

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Energie-Esperimenti

Imaging and diffraction

- 2D imaging (thin structures, surfaces) require soft X or VUV
- 3D imaging (tomography, microscopy, etc) requires hard X, $E > 20$ keV
- XRD (single crystal, powder) require hard X, $E > 5$ keV
- High resolution protein crystallography probably requires $E > 10$ keV

Spectroscopy

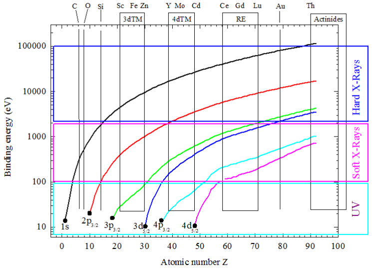
- NON resonant:

Photoemission, usually with UV (surface sensitive), can be done with Hard X to gain bulk sensitivity, but signal is weaker
Inelastic X-ray Scattering, including Compton, hard X-ray $E > 10$

- Resonant:

X-ray Absorption, including EXAFS: $0.2 - 20$ keV, where edges are
RIXS: best in soft X, few cases in tender and hard

Absorption edges



MariX

Macchina piú simile in programma LCLS II (limite di energia 7 keV a 1 MHz mentre MariX dovrebbe arrivare a 13 keV). Lista esperimenti previsti per LCLS II:

Fundamental Dynamics of Energy & Charge
- Dynamic molecular reaction microscope
- Time-resolved photoemission spectroscopy
- Time-resolved Hard X-ray scattering
- New nonlinear X-ray spectroscopies

Catalysis & Photo-catalysis
- Time-resolved resonant inelastic X-ray scattering and absorption spectroscopy
- Time-resolved X-ray photoelectron spectroscopy
- Simultaneous soft X-rays (spectroscopy) and hard X-rays (scattering)
- X-ray photon correlation spectroscopy
- New nonlinear X-ray spectroscopies

Emergent Phenomena in Quantum Materials
- Time-resolved and high-resolution resonant inelastic X-ray scattering
- Time-resolved X-ray dichroism and coherent scattering/imaging
- Time- and spin-resolved hard X-ray photoemission
- X-ray photon correlation spectroscopy

Nanoscale Materials Dynamics, Heterogeneity & Fluctuations
- X-ray photon correlation spectroscopy
- Time-resolved X-ray scattering

Matter in Extreme Environments
- Time-resolved X-ray scattering
- Time-resolved X-ray Thomson scattering/X-ray spectroscopy
- Simultaneous soft X-rays (spectroscopy) and hard X-rays (scattering)

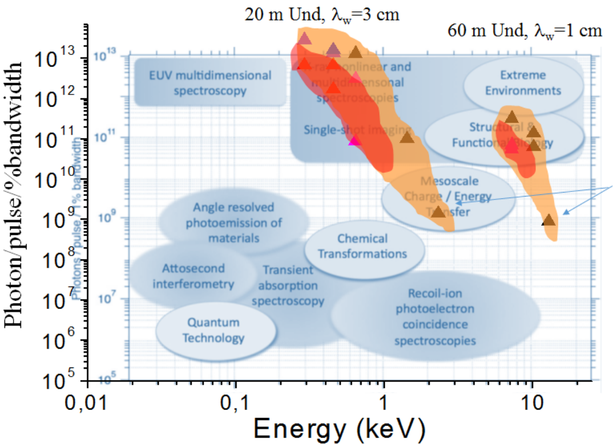
Revealing Biological Function
- Time-resolved X-ray scattering
- Time-resolved resonant inelastic X-ray scattering/spectroscopy

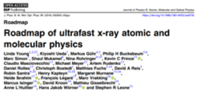
Multidimensional X-ray spectroscopy

Heterogeneous Ensembles: Fluctuations, Structure & Function

High-speed Chemically-Selective Imaging

NEW SCIENCE OPPORTUNITIES
ENABLED BY LCLS-II X-RAY LASERS




Roadmap
Roadmap of ultrafast x-ray atomic and molecular physics

courtesy V.Petrillo