Advances at EUCALL RIs

Graham Appleby – European XFEL Facility

This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 654220

Overview

- Light sources and their developments
  - Synchrotron, XFEL, optical laser driven sources
  - EUCALL
  - Comparison of capabilities and strengths
- Highlight of Experimental capabilities
- Challenges
  - Non-linearity
  - Ultrafast magnetism
- Summary

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Light Sources in Europe

- Accelerator-based RIs (SR, FEL)
  - Successful and large user program
  - Increasing complexity (OLs, FELs, …)
  - X-rays reach diffraction limit & non-linear regime
  - Optical laser methods applied
- Optical-laser based RIs (ELI, LLE faci.)
  - High power laser (HPL)
  - New and ramping up
  - HPLs as sources of UV and x-ray beams
  - UV/x-ray methods provided to users

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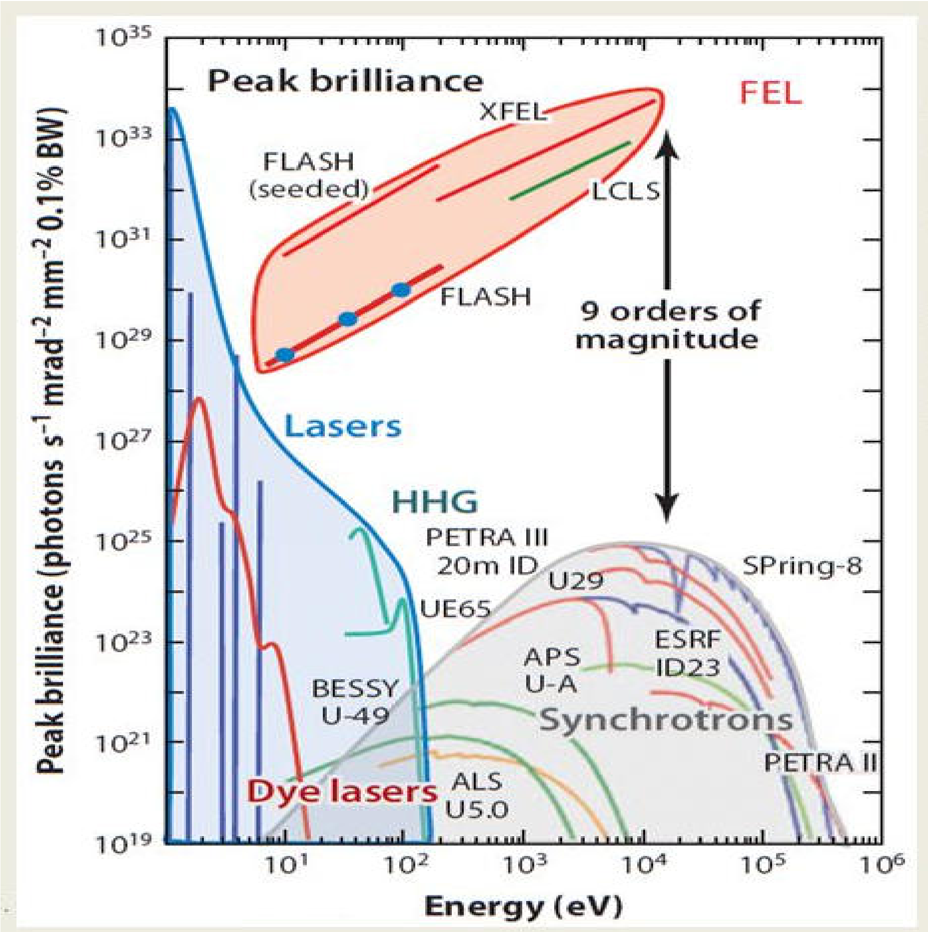
Comparison of light sources



Strength in laser driven sources:
- Ultra short pulses (fs, as)

- Well synchronized with other lasers, for advanced pump-probe experiments

[jitter free]

J. Ullrich et al., Ann. Rev. Phys Chem. **63**, 635 (2012)

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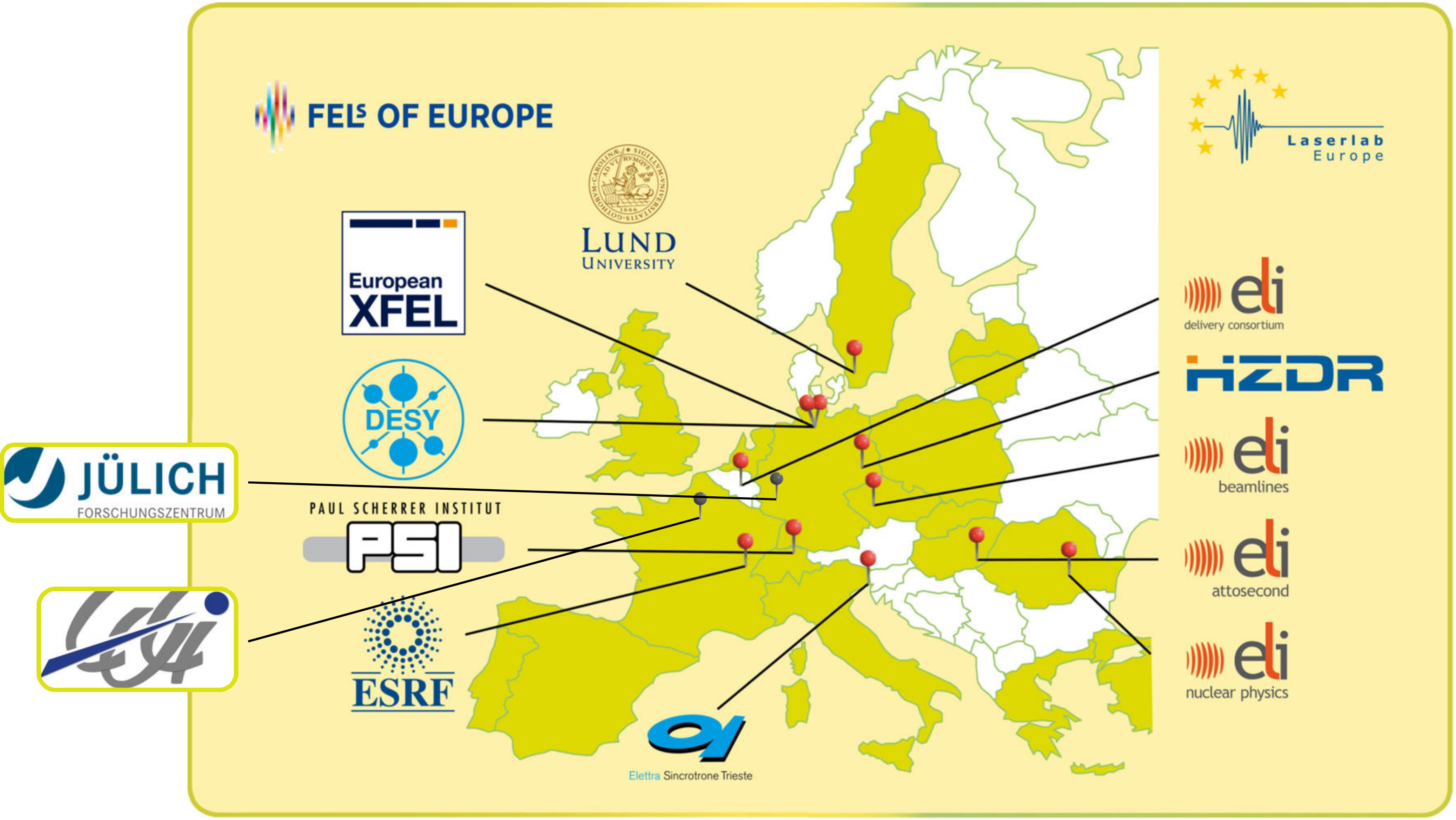
European Cluster of Advanced Laser Light Sources



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European Cluster of Advanced Laser Light Sources

EUCALL is a network between large-scale user facilities for:

- free-electron laser (FEL) radiation
- synchrotron radiation (SR)
- optical laser radiation

Under EUCALL, they work together on:

- common technologies and research opportunities
- tools to sustain this interaction in the future

F**acts and figures:**

- 7M€ from Horizon 2020 for project period Oct 2015 - Oct 2018
- 11 partners from nine countries, two further clusters, two associate partners

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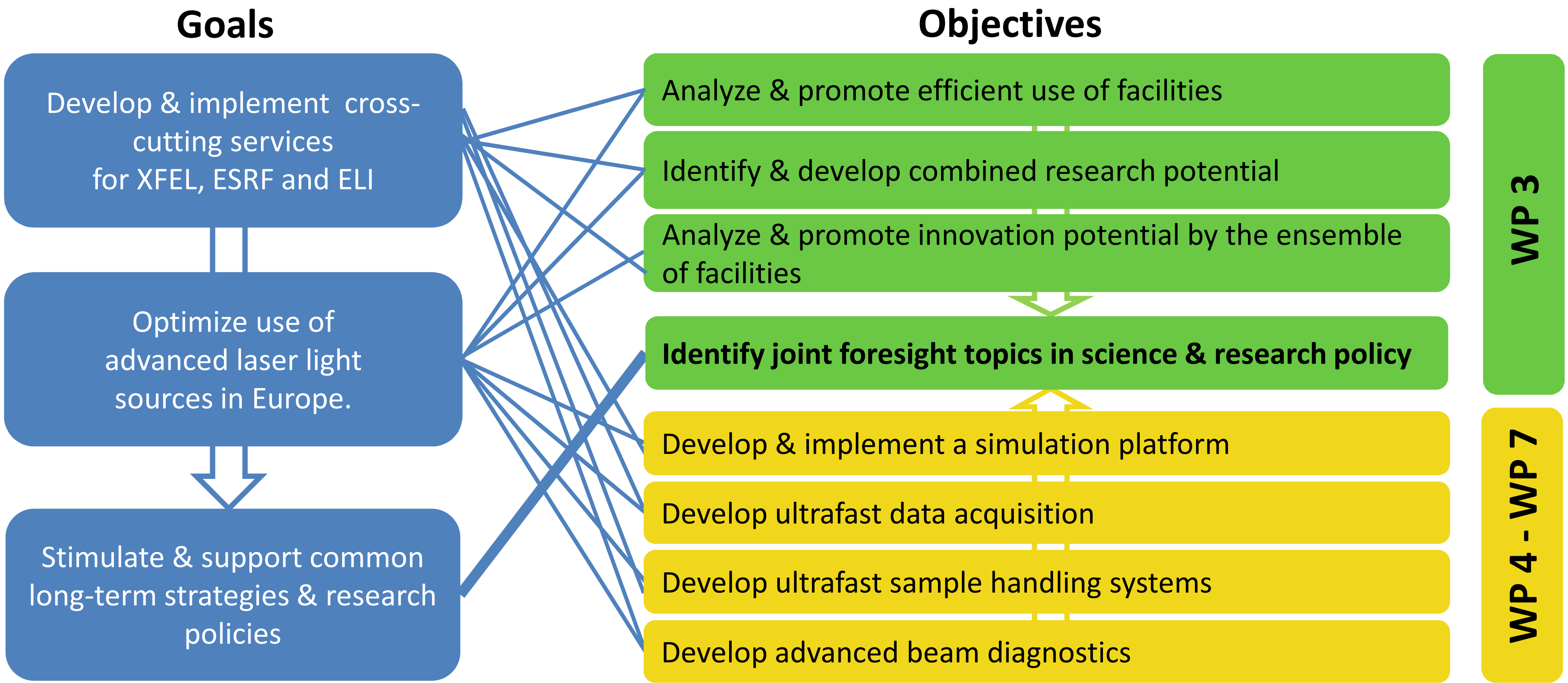
EUCALL's Strategic Goals and Objectives



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Synchrotron facilities





- ~ps pulses
- IR, UV – 200 keV
- Incoherent radiation
- High stability, reliable

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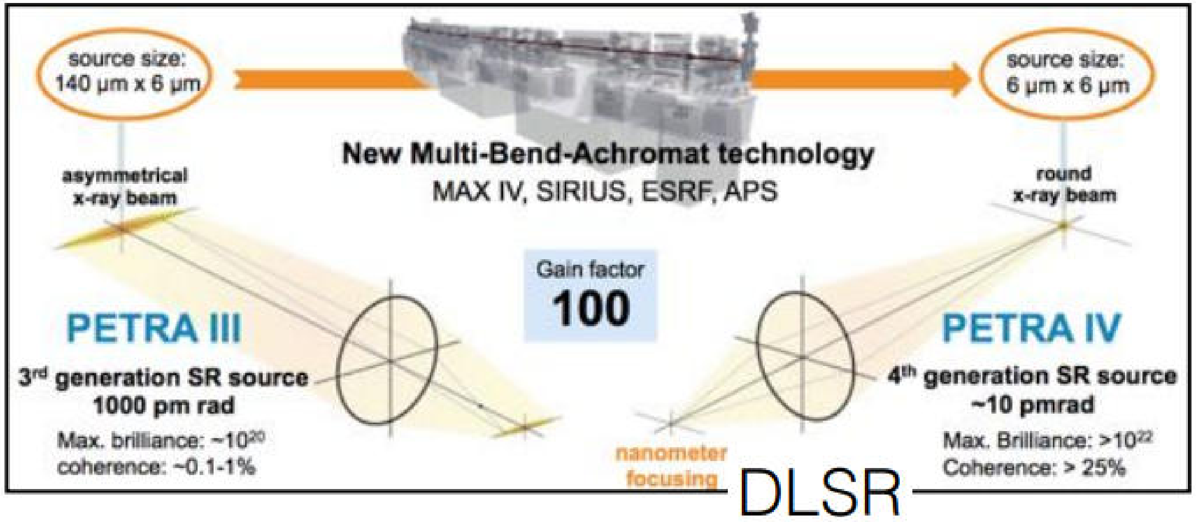
Synchrotron facilities – DLSR upgrades

- Shorter pulses
- Lower emittance
- 100x higher brilliance
- Coherent fraction increased to ~20%



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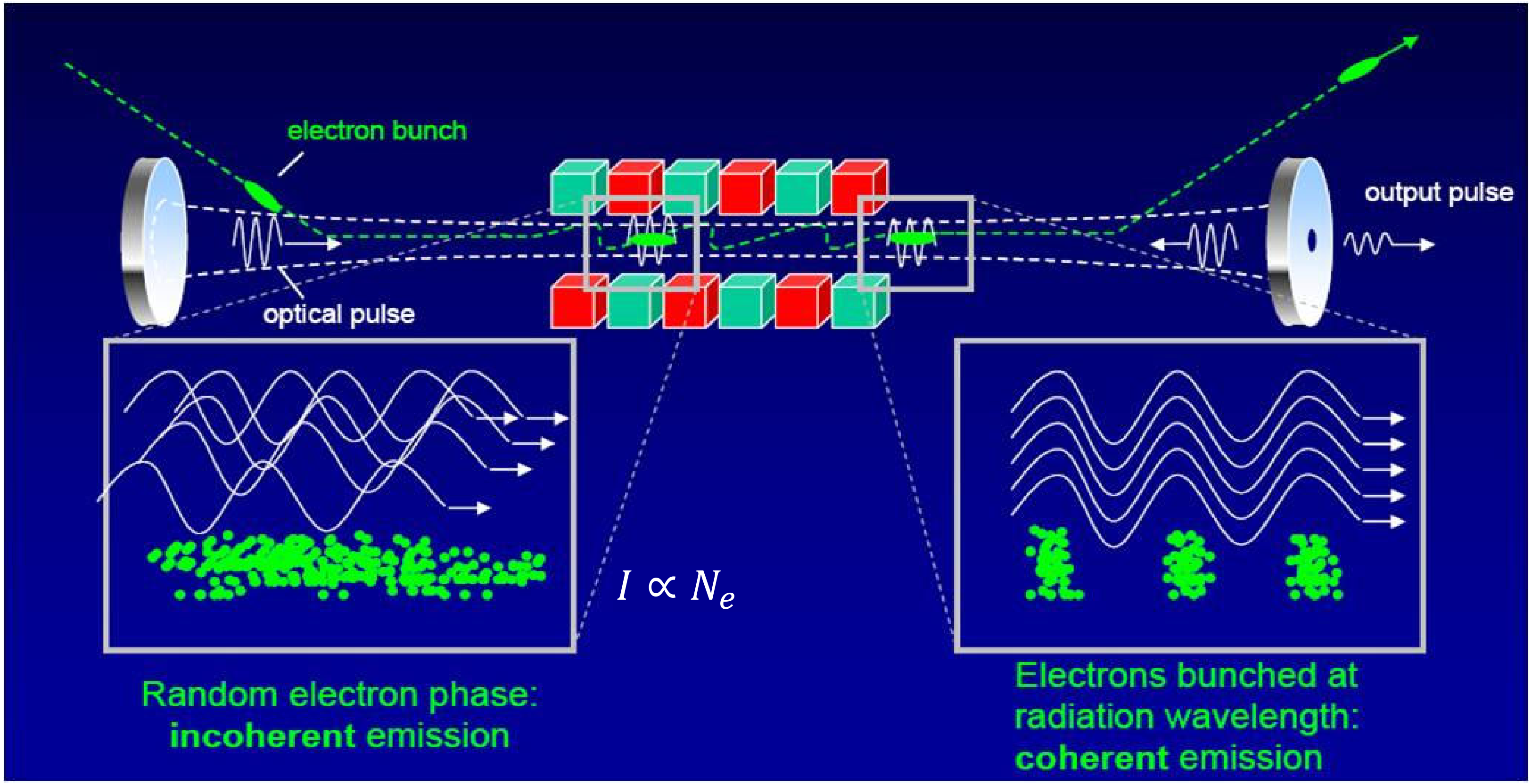
Free-electron laser radiation



$I \propto N_e$

$I \propto N_e^{\,2}$

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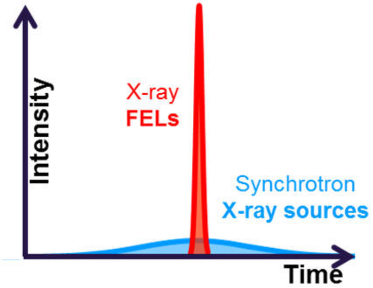
European XFEL and DESY

FEL vs SR

Parameter	Storage Rings	X-ray FEL
Wavelength Range	2-3+ decades typically	1+ decades (multiple undulators)
Peak Brightness (ph/s/mr^2/mm^2/0.1%BW)	$10^{22} – 10^{24}$	$10^{31} – 10^{33}$ (10^9 times higher than SR)
Average Brightness (ph/s/mr^2/mm^2/0.1%BW)	$10^{19}– 10^{21}$	$10^{20}– 10^{22}$
Minimum Pulse Width (fs)	~10,000	~5
Coherence	Limited transverse spatial coherence	Transverse spatial coherence, limited temporal coherence without seeding
Stability: Energy	<.01% (with ~0.1% energy spread)	0.01-0.03% wo / self seeding
Stability: Position	< 0.1 σ (~10 μm H, ~0.3 μm V)	~0.1 σ
Stability: Time	< 0.1 σ (~1 ps, ~0.2 ps low α)	~100 fs
Number of Beamlines	Large (~30-60)	Limited (6 endstations per undulator)



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FELs around the world

- M. Altarelli, MPI

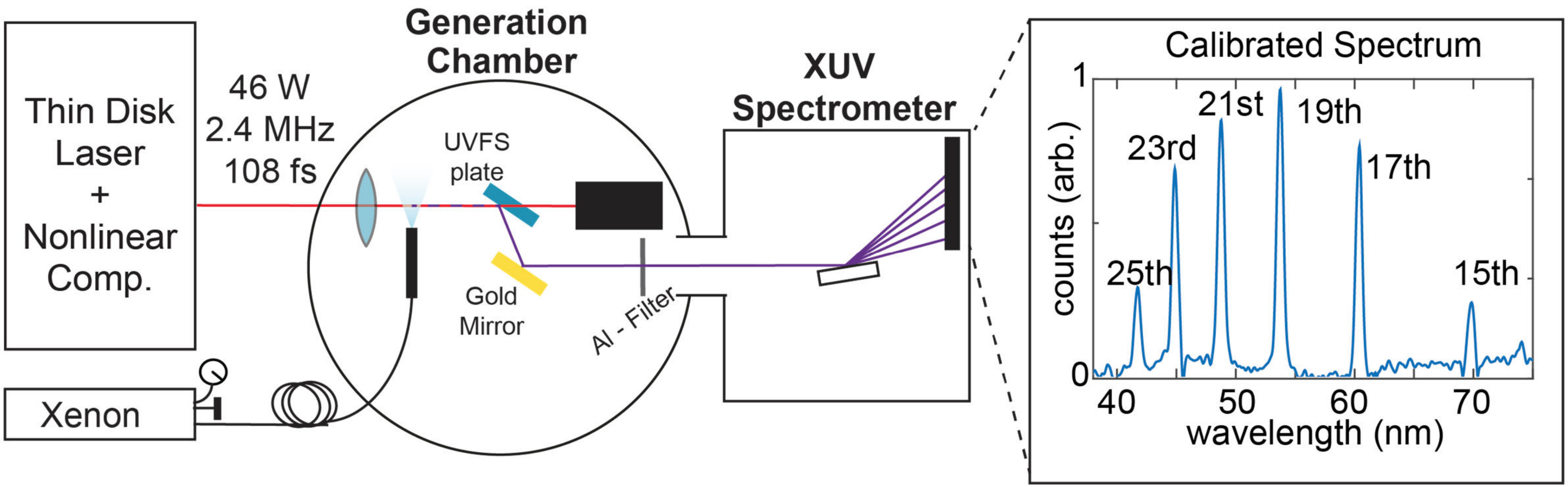
X-ray FEL's worldwide I

Facility	FLASH, GERMANY	LCLS I, US	SACLA, JP	FERMI, ITALY S	PAL-XFEL, KR	DCLS, DALIAN, China S
Max. electron energy (GeV)	1.25	14.3	8.5	1.5	10	0.3
Wavelength range (nm)	3-55	0.1–4.4	0.06–0.3	4 - 100	0.06–10	50 - 150
Photons/pulse	~ 3 X 10^{13}	~ 10^{12}	2 x 10^{11}	10^{13} - 10^{14}	10^{11}–10^{13}	1.4 X 10^{14}
Peak brilliance	1 X 10^{31}	2 x 10^{33}	1 x 10^{33}	10^{31}	1.3 x 10^{33}	
Pulses/second	5000 - (8000)	120	60	10 (50)	60	1 - 50
Date of first beam	2000	2009	2011	2011	2016	2016/2017

X-ray FEL's worldwide, II

Facility	European XFEL	SWISS-FEL, CH	Shanghai FEL-TF, China S	Shanghai FEL-UF, China S	LCLS II, US	Shanghai SCRF
Max. electron energy (GeV)	17.5	5.8	0.8 GeV (1.6)	1.6	4 (=>8?)	8
Wavelength range (nm)	0.05–4.7	0.1 – 7	3 – 10 (2 – 40)	1.2 – 10	0.25 – 4.7	0.05 – 3.3
Photons/pulse	~ 10^{12}	~3.6 X 10^{10}			2 10^{11} – 2 10^{10}	~ 10^{11} - 10^{12}
Peak brilliance	5 x 10^{33}	7 X 10^{32}				
Pulses/second	27 000	100	10 - 50	10 - 50	10^5 - 10^6	10^6
Date of first beam	2017	2017/18	2017	2019	2021	2022/23

Laser driven UV/x-ray sources: High Harmonic Generation



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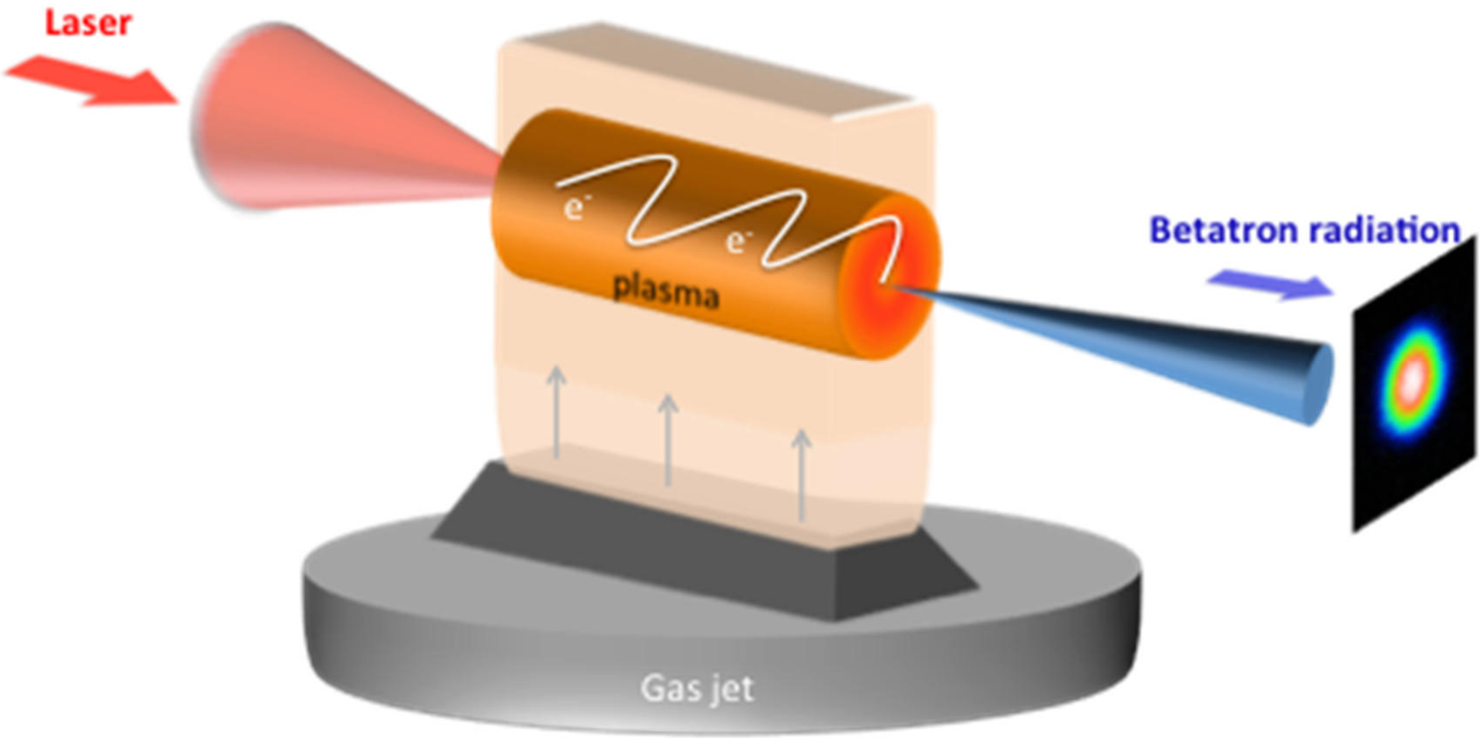
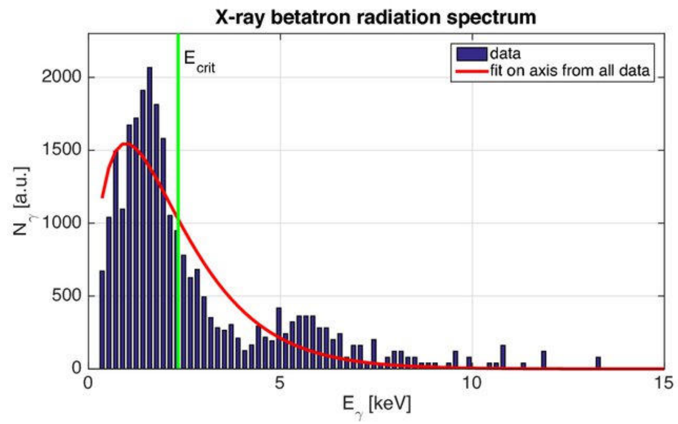
Laser driven UV/x-ray sources: Betatron source





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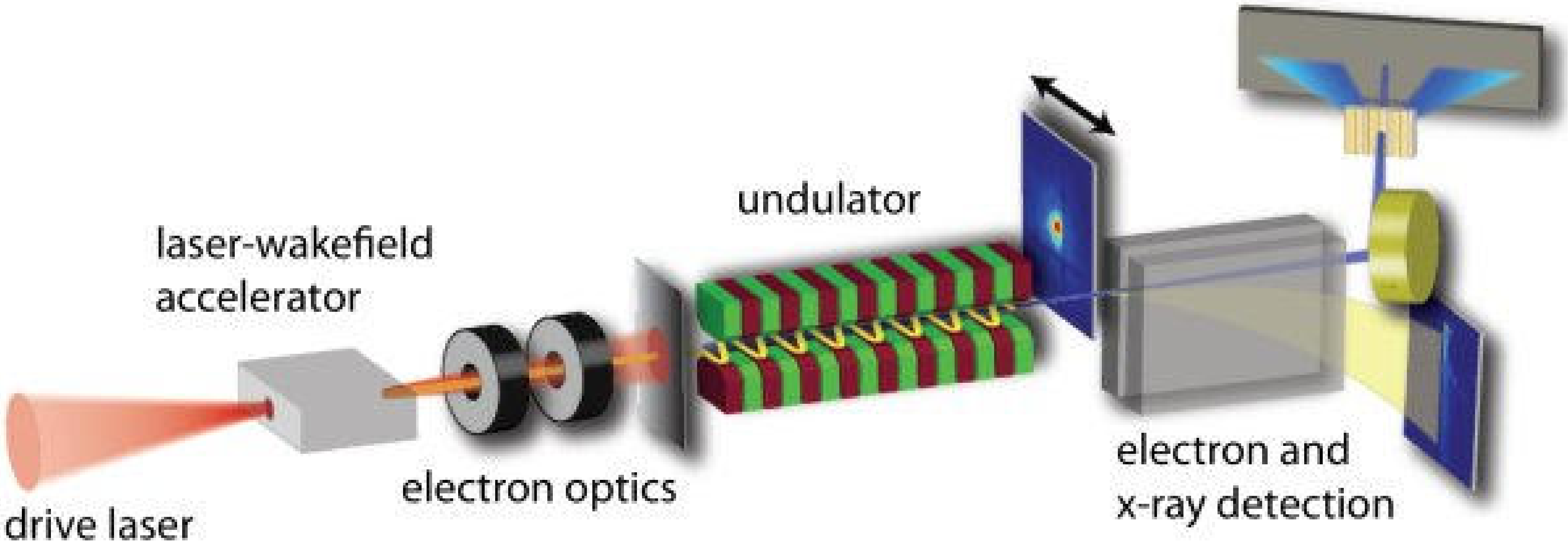
Laser driven UV/x-ray sources: laser-wakefield + undulator



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Suite of advanced experimental capabilities

- Femotsecond and sub-femtosecond pulses of UV, soft x-ray, (very) hard x-ray
- High intensity, narrow focus
- X-ray diffraction & scattering, absorption&emission spectroscopy, imaging …
- Optical lasers for pump-probe measurements (at ELI, jitter free)
  - ► Variable time-delay – [-47 – 50 ps with 1 fs steps at SACLA]
- High power optical lasers for dynamic compression
- High repetition rate – FELs from 100s of Hz up to 4.5 MHz
  – High power Optical lasers up to kHz

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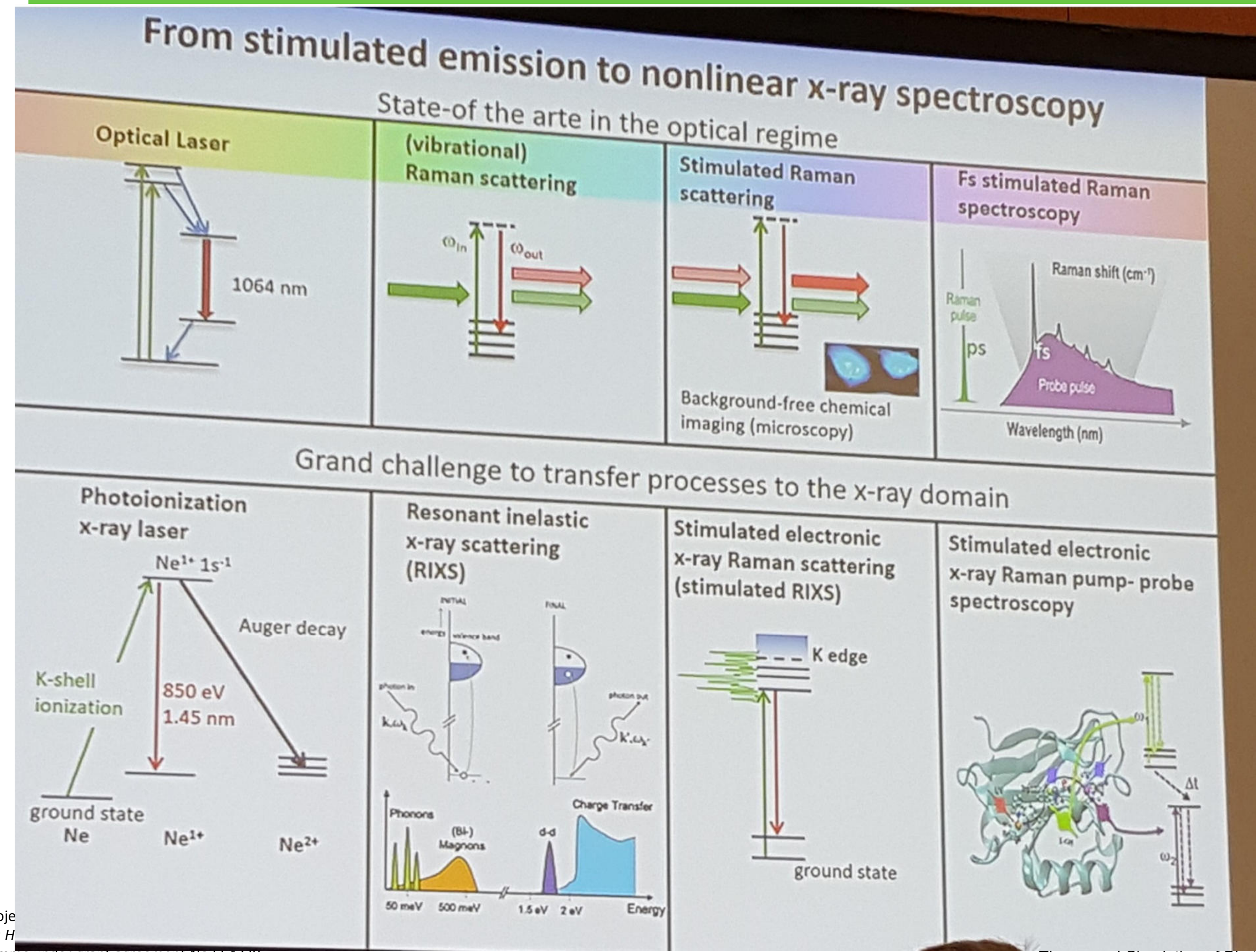

- N. Rohringer (DESY)

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X-ray sources and non-linearity

- Synchrotron – 10^5 ~1 keV photons/ 10^{-11} s on a μm^2 spot
  - ► Synchrotron: $< E_{rms} >$ ~10^5 V/cm

- XFEL – 10^{13} ~1 keV photons/ 7 x 10^{-14} s on a μm^2 spot
  - ► XFEL: $< E_{rms} >$ ~10^{10} V/cm

- $< E_{at} >$ ~ 5 x 10^9 V/cm

(E-field between nucleus and electrons in atom)

Experimentalists often attenuate the XFEL beam to avoid non-linear effects in experiments

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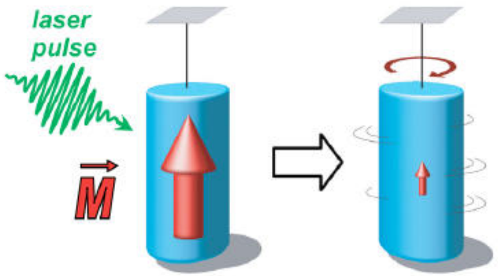
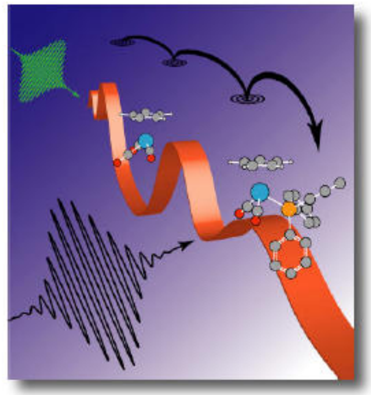
Timescales from nano - attoseconds

- electron dynamics and correlations
- energy transfer processes
- spin dynamics and relaxation
- electronic / structural phase transitions
- nonlinear / nonequilibrium phenomena

10^{-9}	10^{-12}	10^{-15}	10^{-18} s
nano	pico	femto	atto seconds



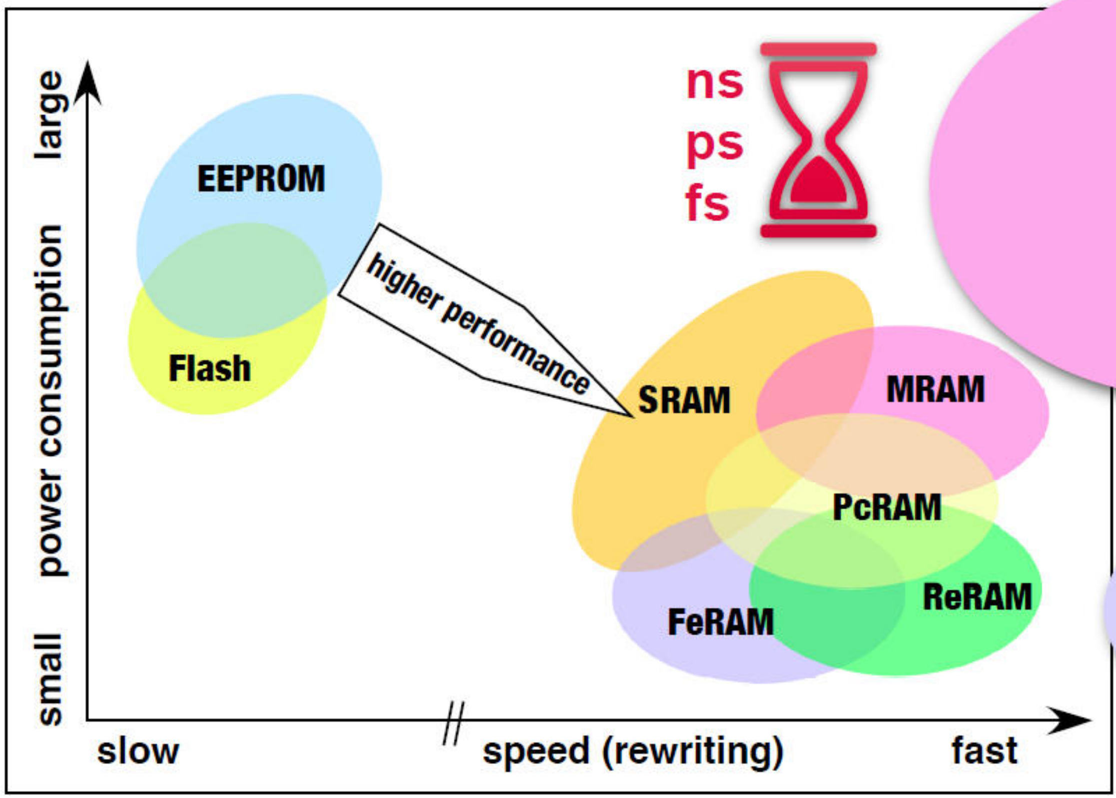
- Core-hole life times
- Shortest light pulses
- Electron scattering
- Vibrations
- Spin dynamics
- Phonons
- Structural Changes

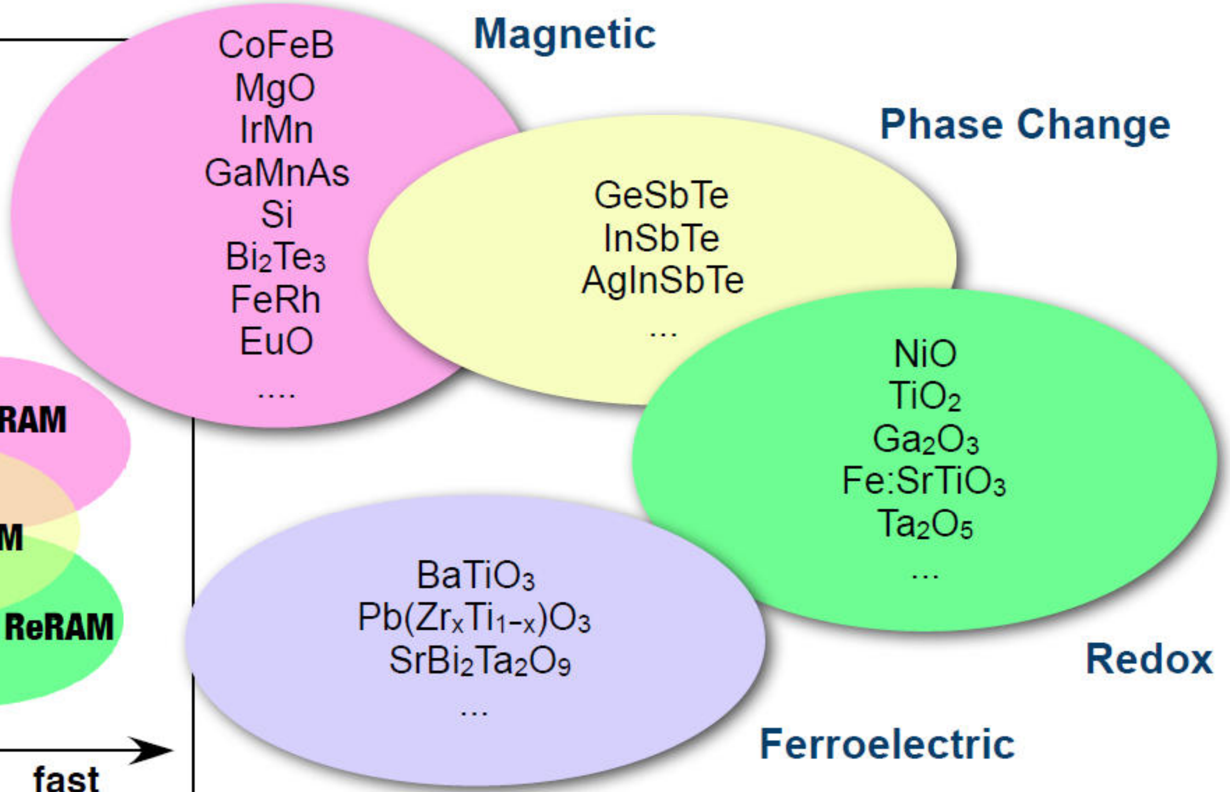


JÜLICH Forschungszentrum

C.-M. Schneider
FZJülich

Challenges for non-volatile memory





- challenge to in-depth characterization – static, dynamic, in-operando

C.-M. Schneider
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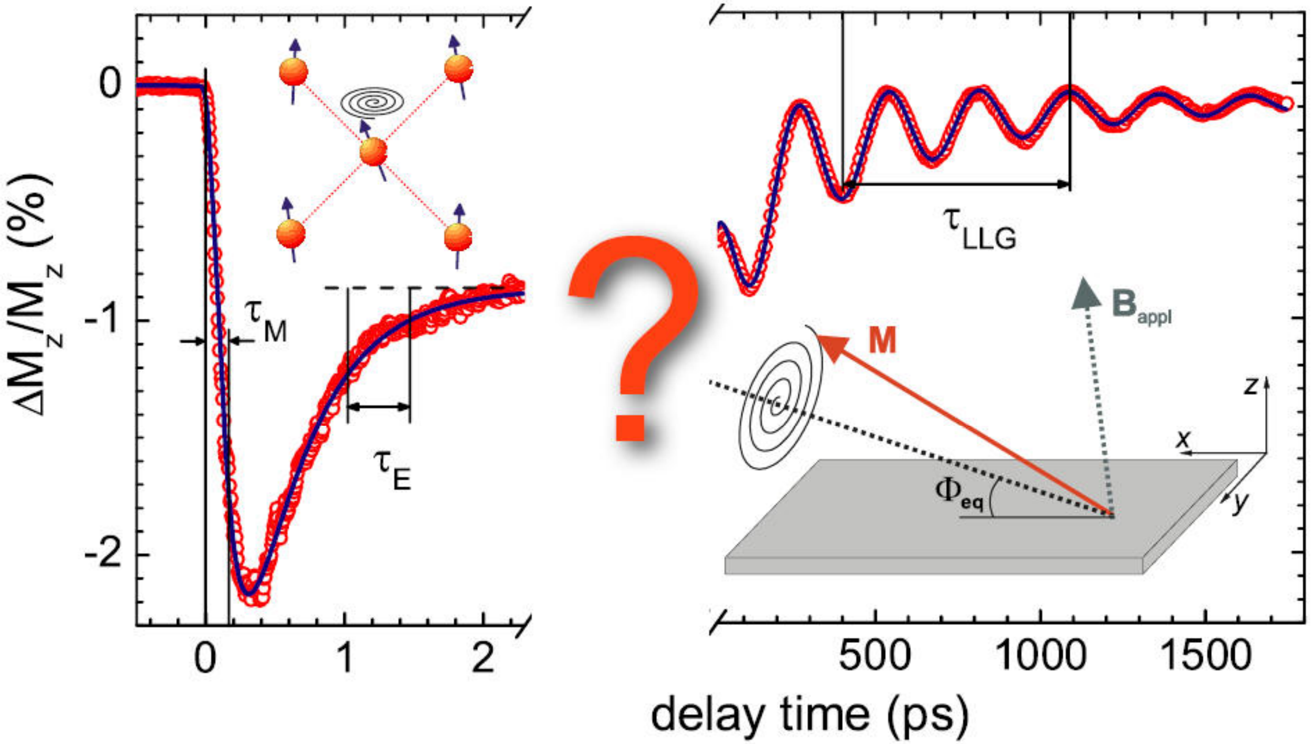
Linking time-scales in magnetism

- there is a whole world between "fast" and "ultrafast"
- linking mechanisms on different time scales
- crucial for understanding ultrafast "switching" and relaxation



Koopmans, B., Ruigrok, J. J. M., Longa, F. D.and De Jonge, W. J. M., *Unifying Ultrafast Magnetization Dynamics*, Phys. Rev. Lett. **95** (2005), 267207-267204.

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Summary

Next 10 years will see big steps forward in experimental capabilities

- synchrotrons and diffraction-limit upgrade (DLSR)
- FELs and upgrades
- optical laser radiation (ELI)

Experiments at modern laser light sources will require

- advances in theory and interpretation of results
- advanced simulations to accompany experiment results

Possible collaborations would be a desired outcome of this meeting

- New collaborations between members of the meeting
- Proposals for funding between a group of instutites

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Possible steps

Possible collaborations would be a desired outcome of this meeting

- New collaborations between members of the meeting
- Proposals for funding between a group of instututites

- Collect all presentations and make available on workshop website
- Mailing list for all participants – theory@eucall.eu
- ?

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Thank you for your attention

www.eucall.eu / contact@eucall.eu

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