The BESSY - FEL Collaboration

Planning the Revolution for Research with soft X-Rays

Photon Energy Range :	**20 eV up to 1 keV**
$\Delta\lambda/\lambda$	**10^{-2} to 10^{-4}**
Peak Power:	**1mJ in 200 fs >> 5 GW**
Time Structure:	**200 fs (< 20 fs with seeding)**
Pulse Sequence:	**1 kHz with 1-25 micropulses**
Peak Brilliance:	**> 10^{31} Ph./(secmm^{2}mrad^{2}0.1%BW)**

New Records in spectral, spatial, and time resolution

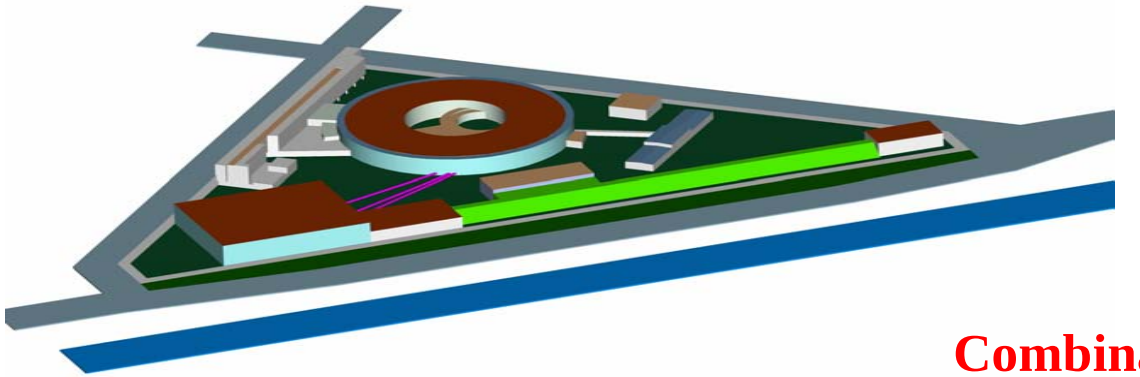
Two Color Pump Probe Experiments

Transverse Coherent Beam

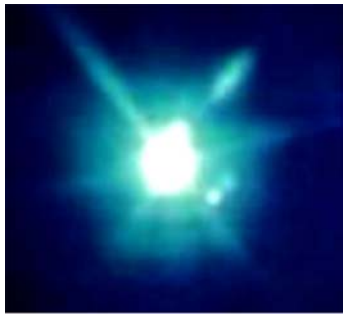
Technische Universität Dresden

TSB TECHNOLOGIESTIFTUNG INNOVATIONSZENTRUM BERLIN

Zukunftsfonds des Landes Berlin

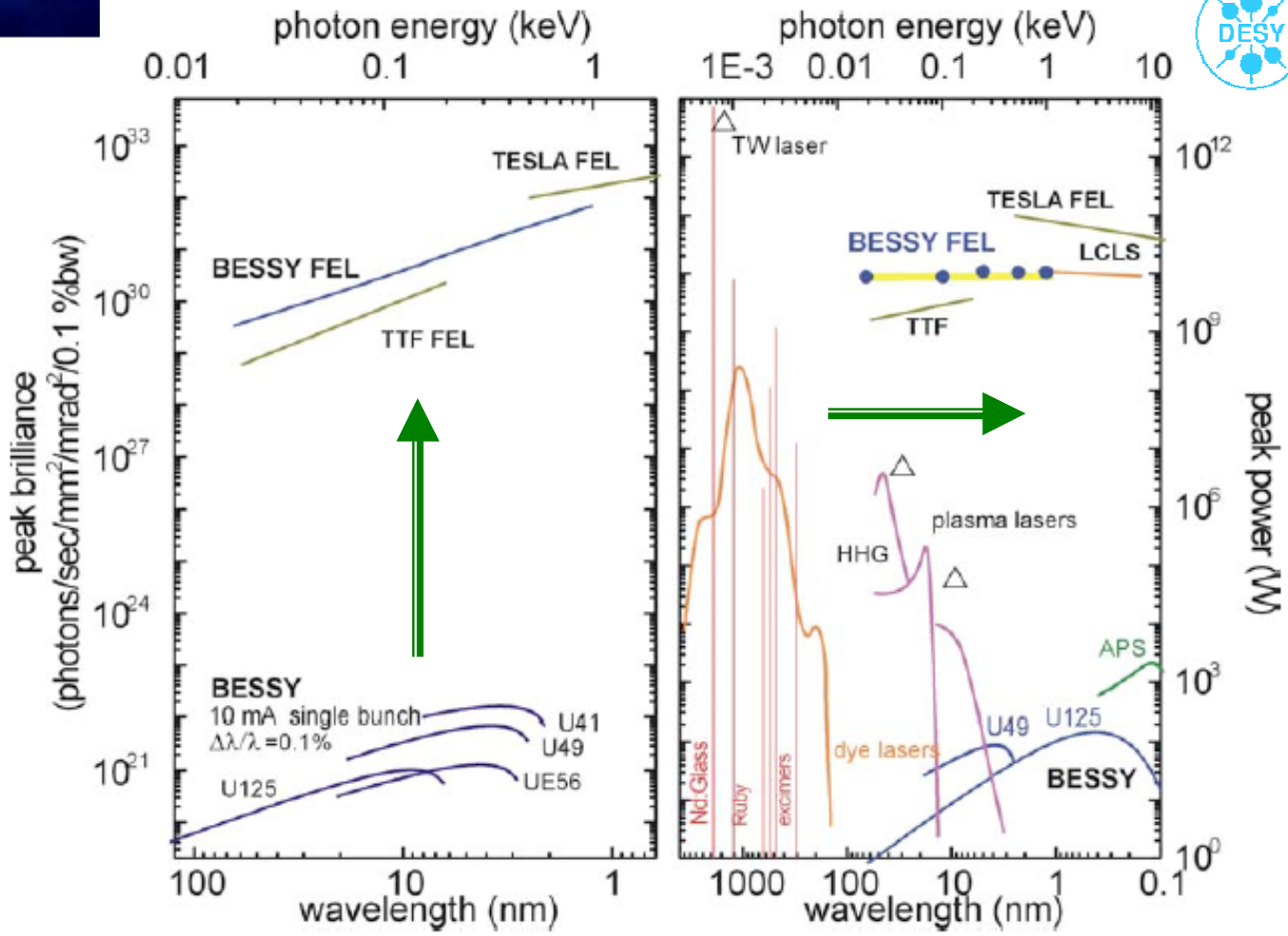


Combination with BESSY II

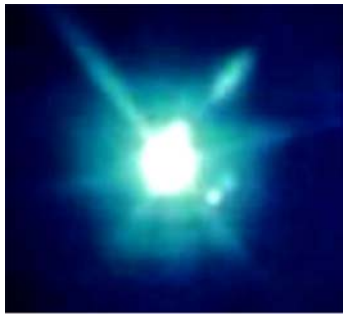


The BESSY Soft X-Ray SASE FEL

Peak Power and Brilliance



Experiments can be more readily extrapolated by the LASER community than by the synchrotron radiation community



The BESSY Soft X-Ray SASE FEL
Increasing the Performance

- **Peak brilliance** **exceeds existing x-ray sources by** $> 10^9$

Brilliance **B** determines coherence "degeneracy parameter": $\Delta \sim B \times \lambda^3$

coherence volume 1 x 5 x 50µm

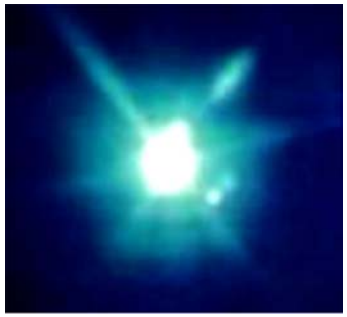
contains < 1 photon

coherence volume 0.1 x 100 x 100µm

contains 10^9 photons

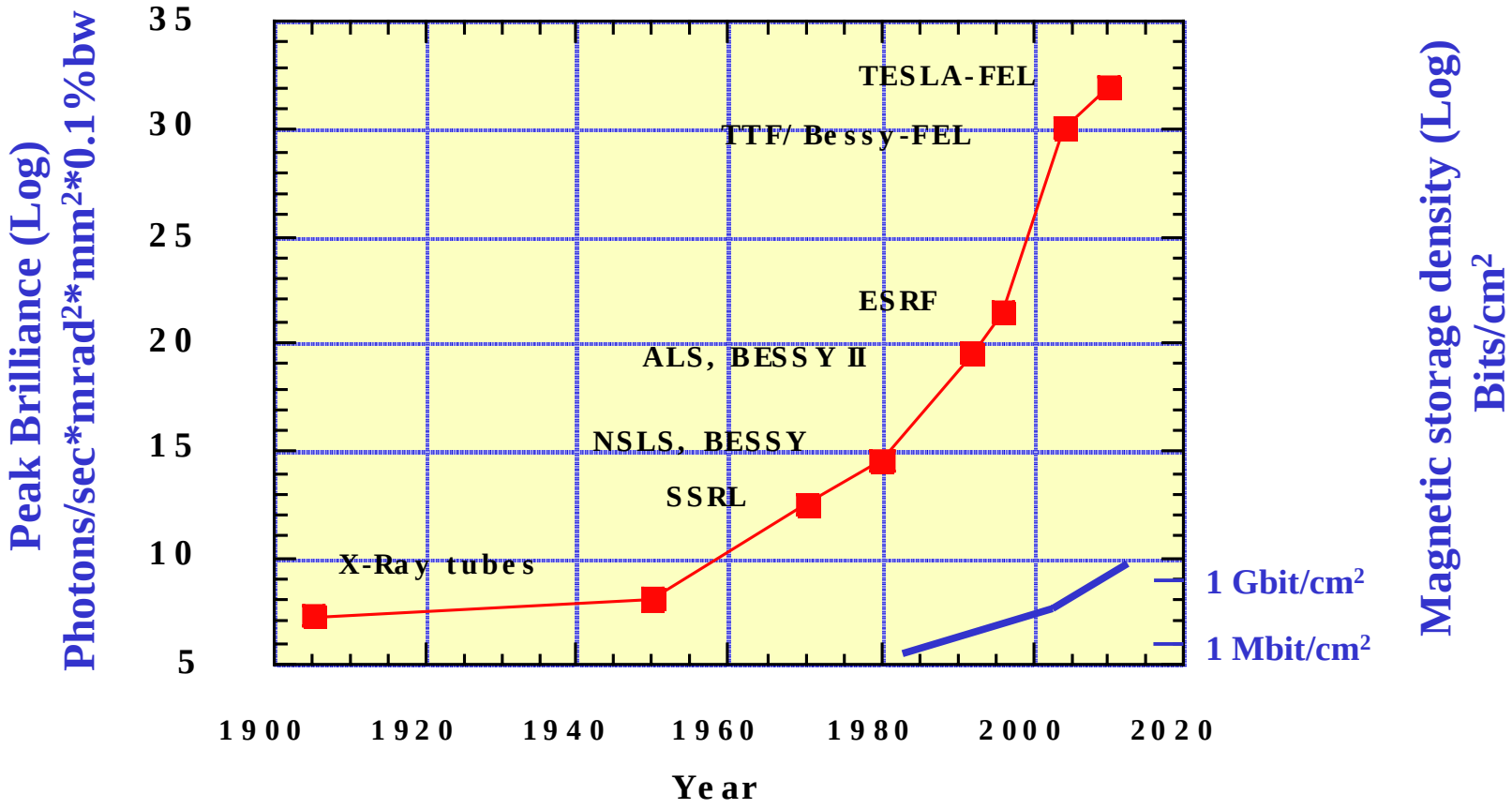
All present experiments at synchrotrons are based on one photon processes
FELs have 10^9 equivalent photons

- **Time resolution** exceeds 3rd gen. synchrotron sources by a factor > 10^3

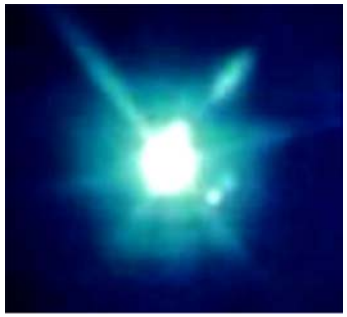


The BESSY Soft X-Ray SASE FEL

Increasing the Performance

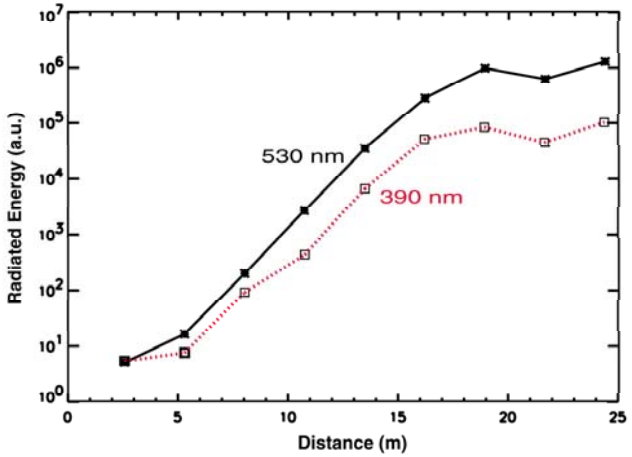


The development of (soft) X-Ray sources easily outpaces the growth of the semiconductor and magnetic storage technology

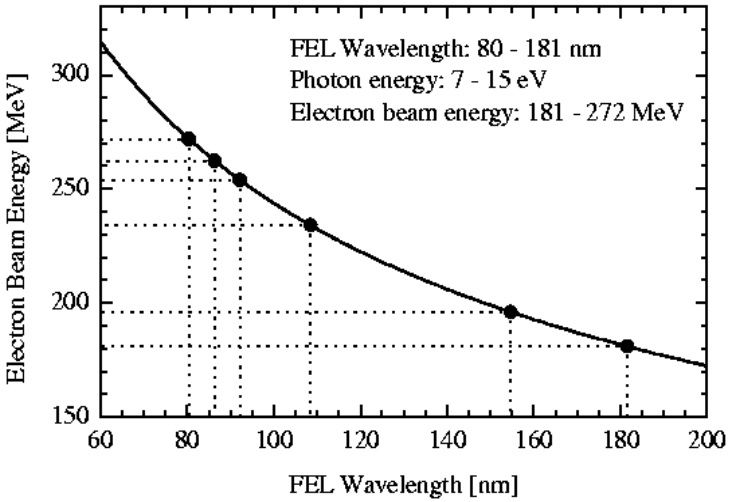


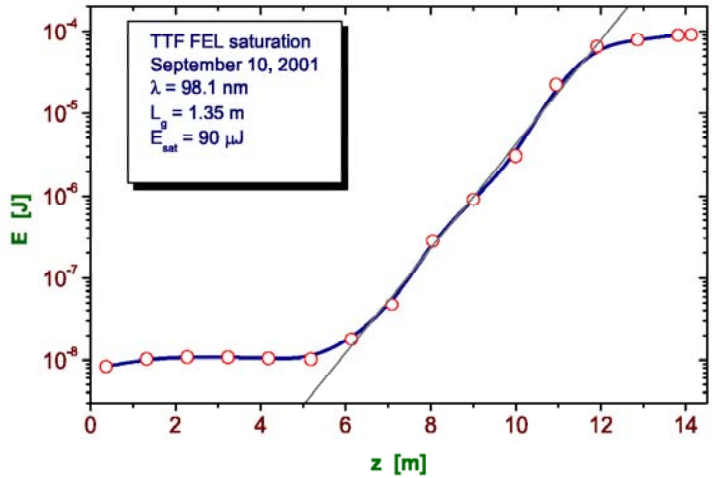
The BESSY Soft X-Ray SASE FEL
Verification of the SASE Process

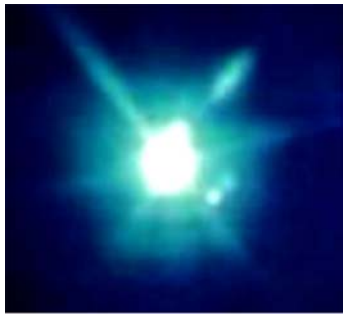
Results from LEUTL, APS =====>
SASE saturation at 530 and 390 nm



Results from TESLA TTF at DESY
Gain and saturation at wavelengths below 100 nm

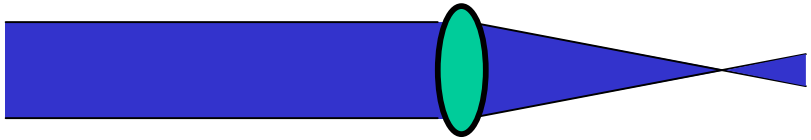






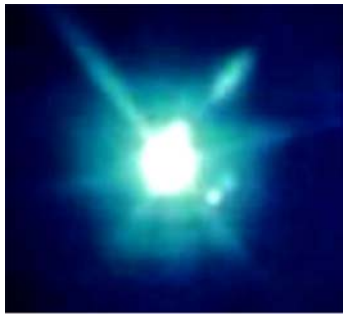
The BESSY Soft X-Ray SASE FEL
Probe and Manipulate Matter

Average Power 1W (1 mJ x 1 kHz)
Peak Power 5 GW (1 mJ / 200 fs)



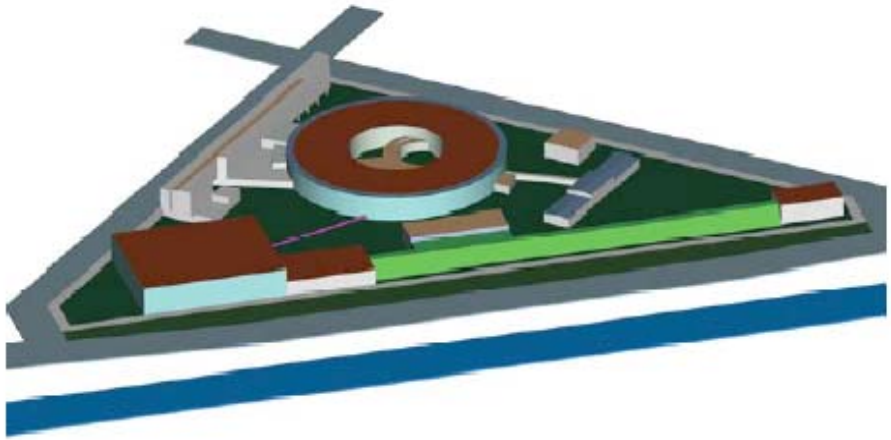
By variation of the focussing parameters the power density
can be adjusted by 8 orders of magnitude
(focal spot variation from 1μm^2 to 1cm^2)

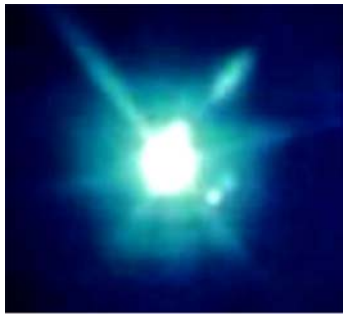
The experiences of the LASER community can be exploited in dealing with these power loads



The BESSY Soft X-Ray SASE FEL

COMPLEMENTARITY of the VUV and X-RAY FEL

VUV and SOFT X-RAYS BESSY FEL		X-RAYS TESLA X-FEL
		
20 eV to 1 keV	**PHOTON ENERGY**	500 eV to 15 keV
1 mJ	**PULSE ENERGY**	1 mJ
200 fs to 20 fs	**PULSE LENGTH**	100 fs
1 kHz (1-25 pulses)	**REPETITION RATE**	5 Hz (7200 pulses)

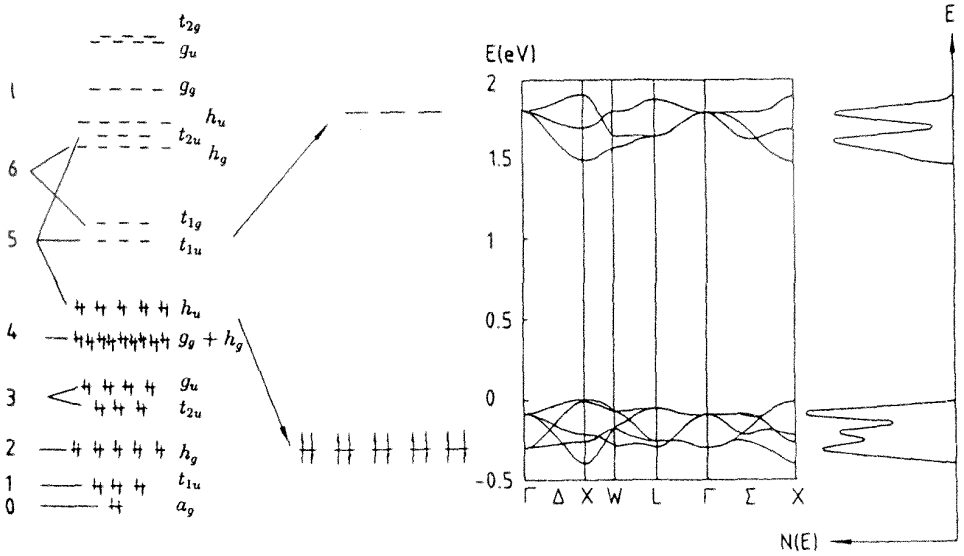


The BESSY Soft X-Ray SASE FEL

COMPLEMENTARITY of the VUV and X-RAY FEL

Structure and Electronic Structure

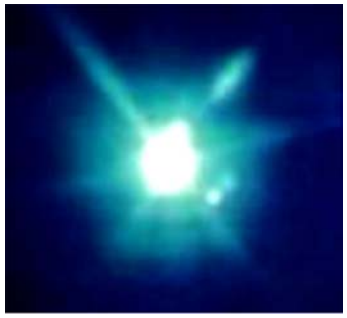
Are needed to develop an understanding of all essential materials properties



MOLECULE SOLID DOS

X-RAYS
TESLA X-FEL

VUV and SOFT X-RAYS
BESSY FEL

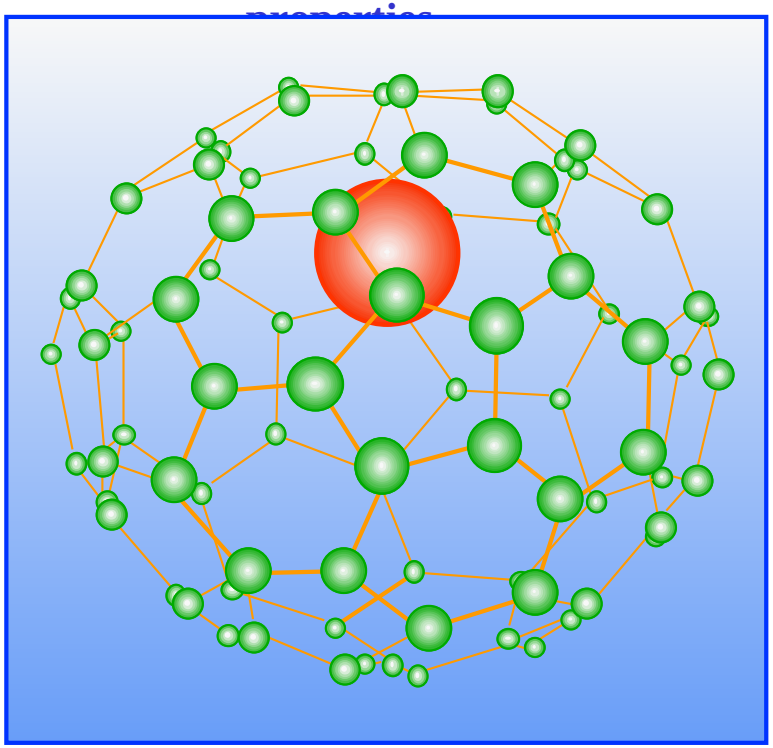


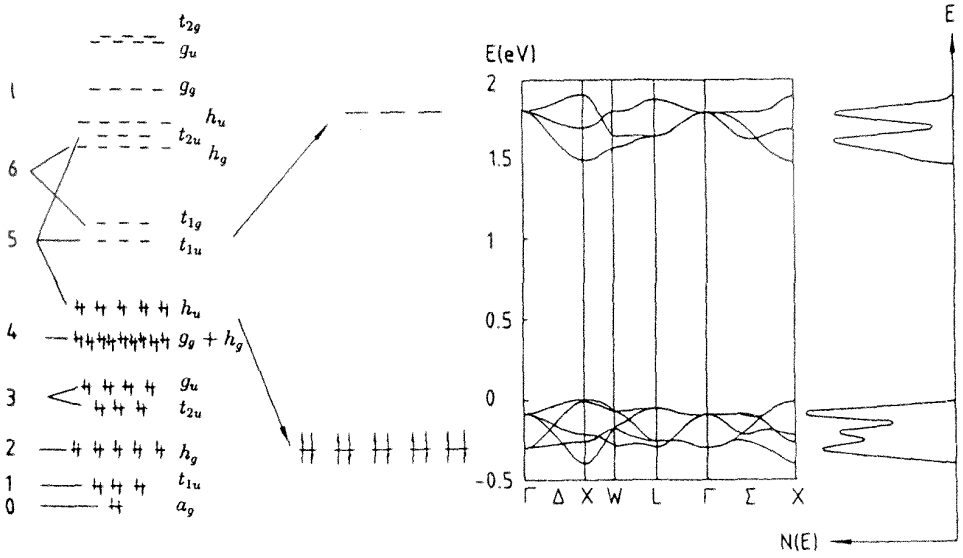
The BESSY Soft X-Ray SASE FEL

COMPLEMENTARITY of the VUV and X-RAY FEL

Structure and Electronic Structure

Are needed to develop an understanding of all essential materials properties

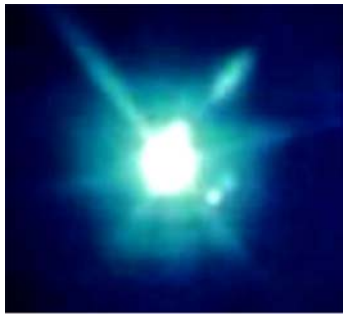




MOLECULE SOLID DOS

X-RAYS
TESLA X-FEL

VUV and SOFT X-RAYS
BESSY FEL



The BESSY Soft X-Ray SASE FEL

COMPLEMENTARITY of the VUV and X-RAY FEL

Research with Synchrotron Radiation in Germany -Present State and Perspectives-

A Study of the National Committee for Research with Synchrotron Radiation

<u>Recommendation (with highest Priority):</u>

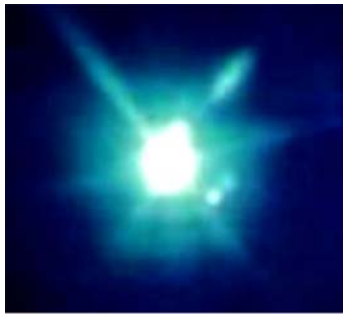
Realization of the two complementary projects,

the X-FELat DESY in Hamburg for hard X-Rays,

for timeresolved struture research, and the BESSY-FEL

for the VUV and Soft X-Ray range, to be used

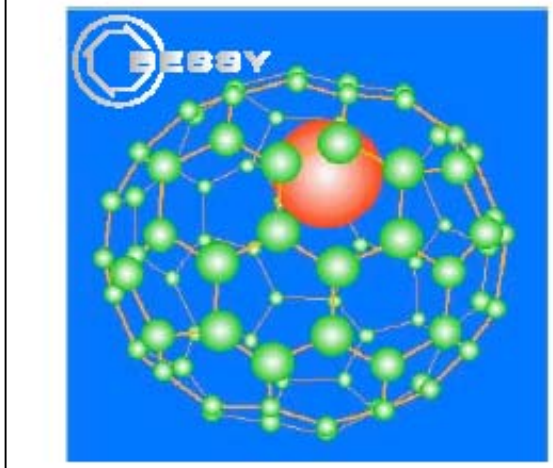
predominantly for investigations of electron dynamics



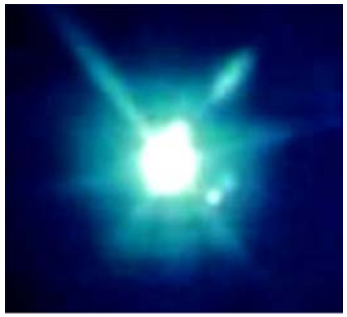
The BESSY Soft X-Ray SASE FEL

Developing the SCIENTIFIC CASE

Two workshops with the prospective user community were organized so far in Blankensee (2000) and in Holzhau (2001)



Future Workshops
Fs Spectroscopy (March 2002) jointly with ALS and SLS
Coherence in the Soft X-Ray Range (Fall 2002) EU financed



The BESSY Soft X-Ray SASE FEL

Visions of SCIENCE

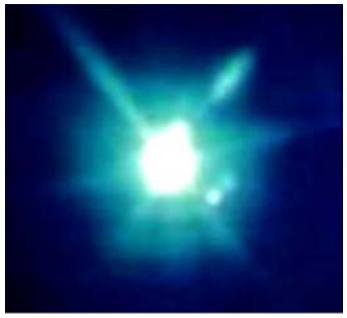
Fs-dynamics ===> Chemical Reactions — CHEMISTRY
Magnetic Nanostructures — MATERIALS SCIENCES
Energy Dissipation in Clusters — PHYSICS

Brightness ===> Complex Solids (Ultra High Resolution, scattering) — PHYSICS
Catalysis, Electrochemistry, Process Monitoring — TECHNOLOGY
Spectromicroscopy — LIFE-/ENVIRONMENTAL SCIENCES

Coherence ===> Time resolved imaging (single pulse) — LIFE-/ MATERIALS-SCIENCES
biological systems and magnetic structures
nanofabrication — TECHNOLGY

Peak Power ===> Clusters — PHYSICS
Atoms and ions in traps, including nonlinear processes — PHYSICS
Athmospheric Chemistry — ENVIRONMENTAL SCIENCES
Fusion Plasmas — TECHNOLOGY

SINGLE PULSE EXPERIMENTS

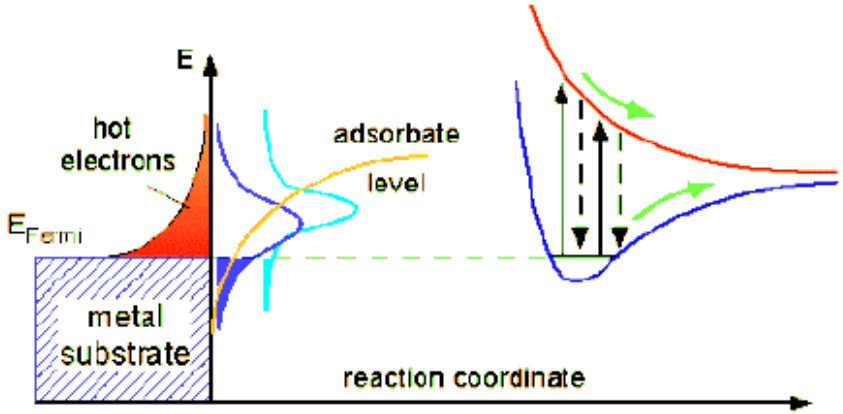


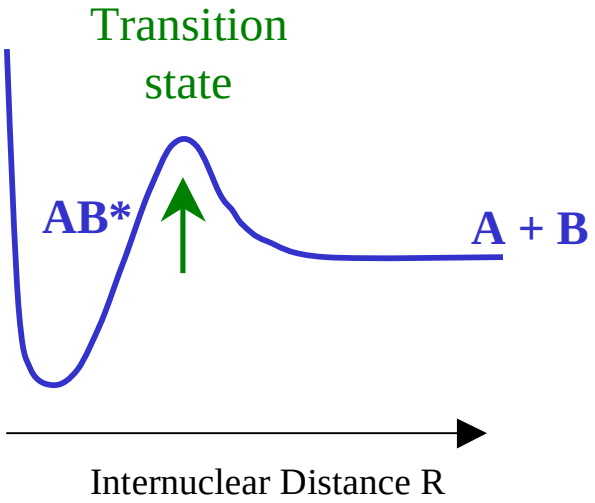
The BESSY Soft X-Ray SASE FEL

Visions of SCIENCE

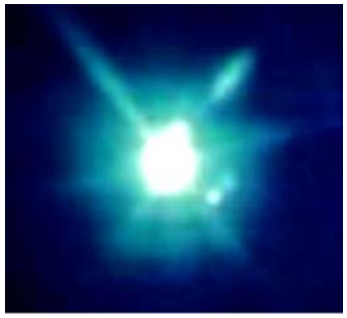
FEMTOCHEMISTRY

at surfaces, in molecules, and clusters





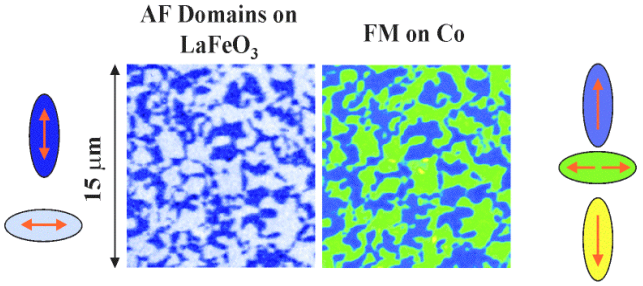
Understanding the dynamics and formation of a chemical bond by time resolved electron spectroscopy



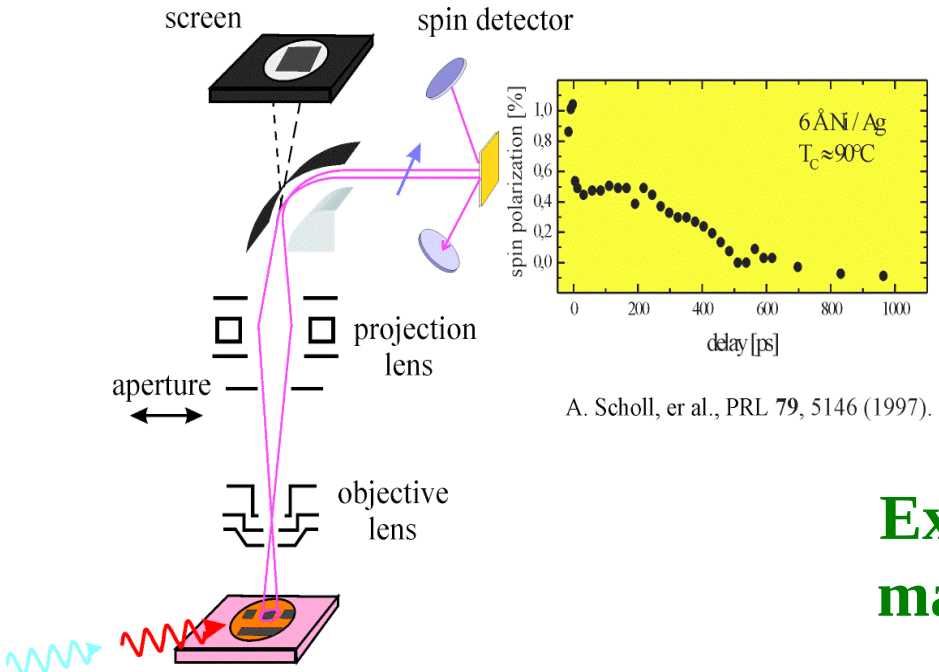
The BESSY Soft X-Ray SASE FEL

Visions of SCIENCE

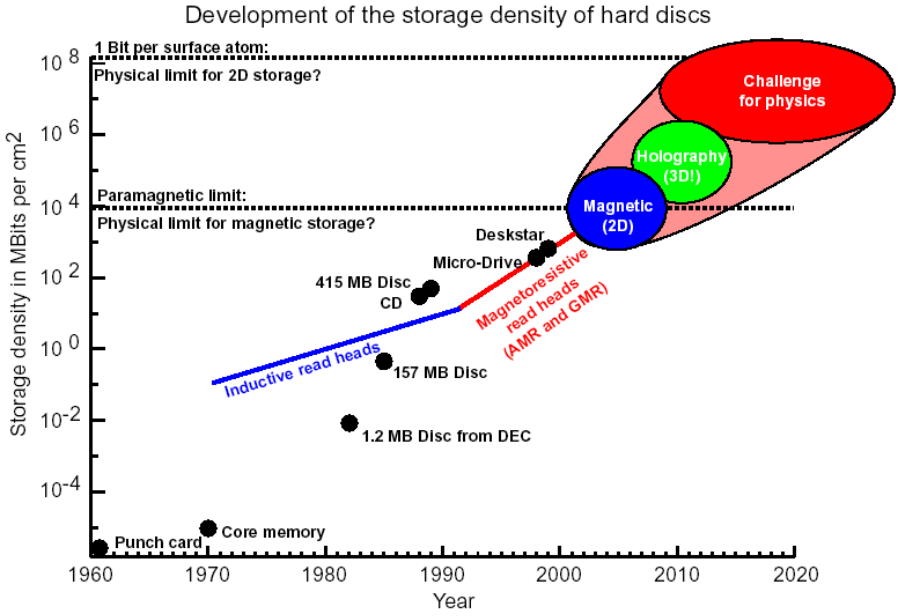
Magnetization dynamics on the nm size scale



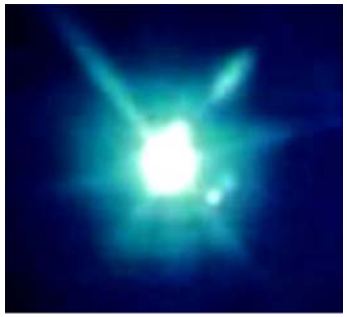
F. Nolting, et. al., Nature **405**, 767 (2000).



A. Scholl, er al., PRL **79**, 5146 (1997).



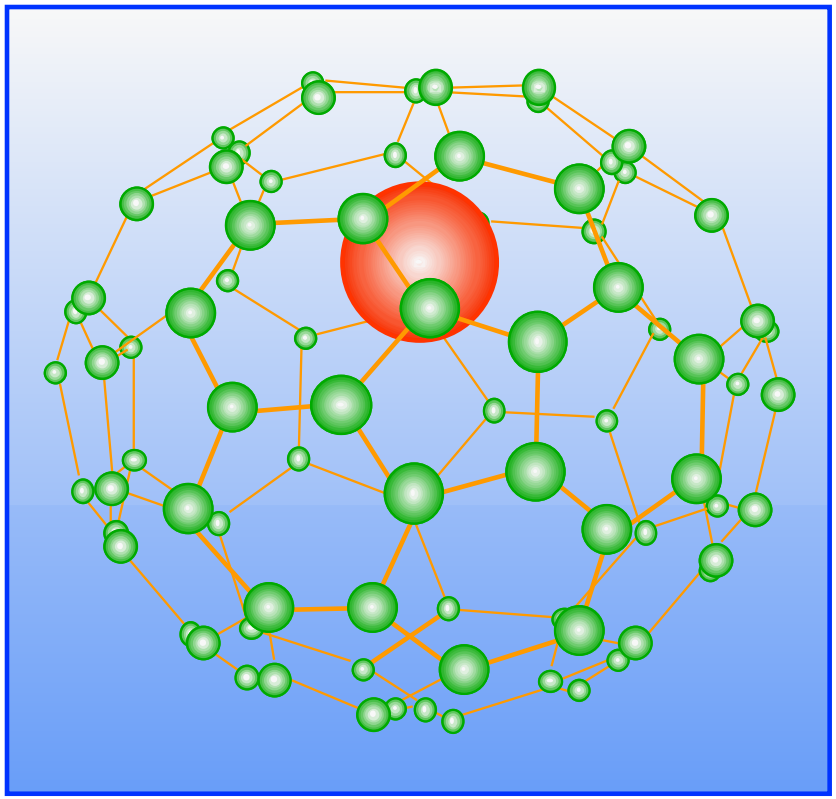
Explore and expand the limits of magnetic data storage technology

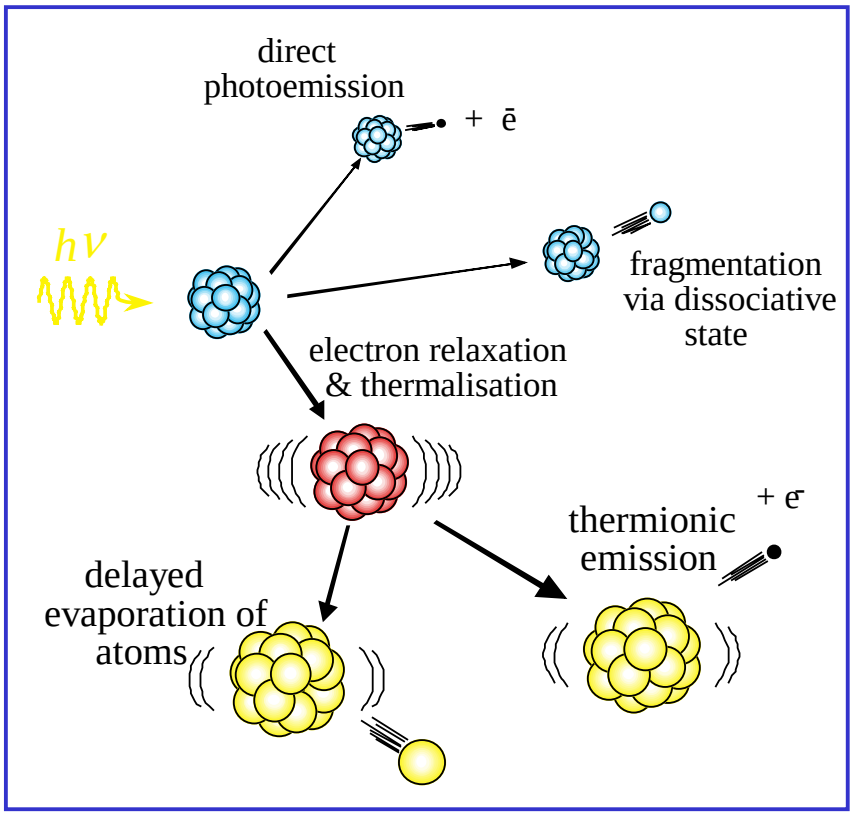


The BESSY Soft X-Ray SASE FEL

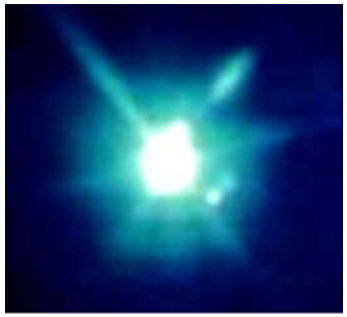
Visions of SCIENCE

Clusters as New Materials





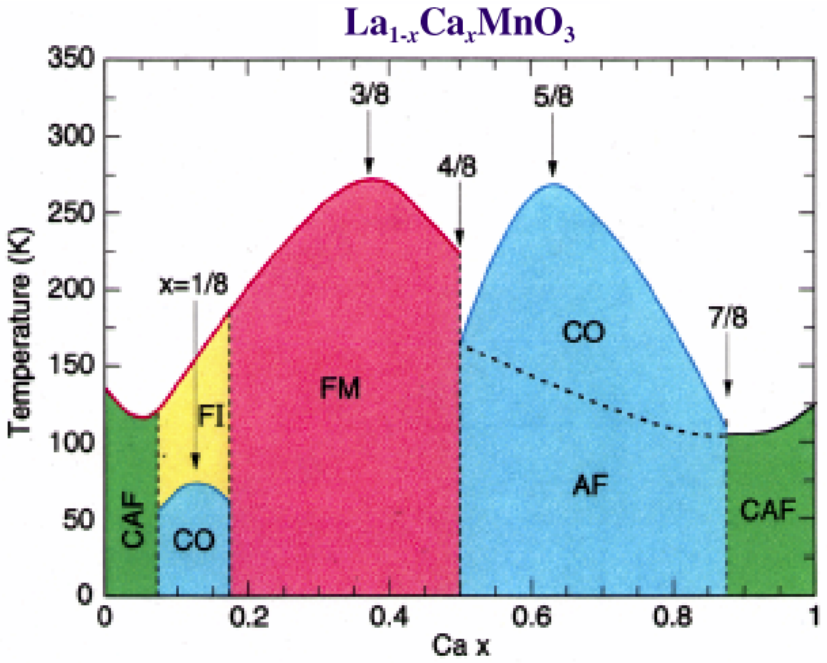
Exploring the materials properties and dynamics of size-selected clusters

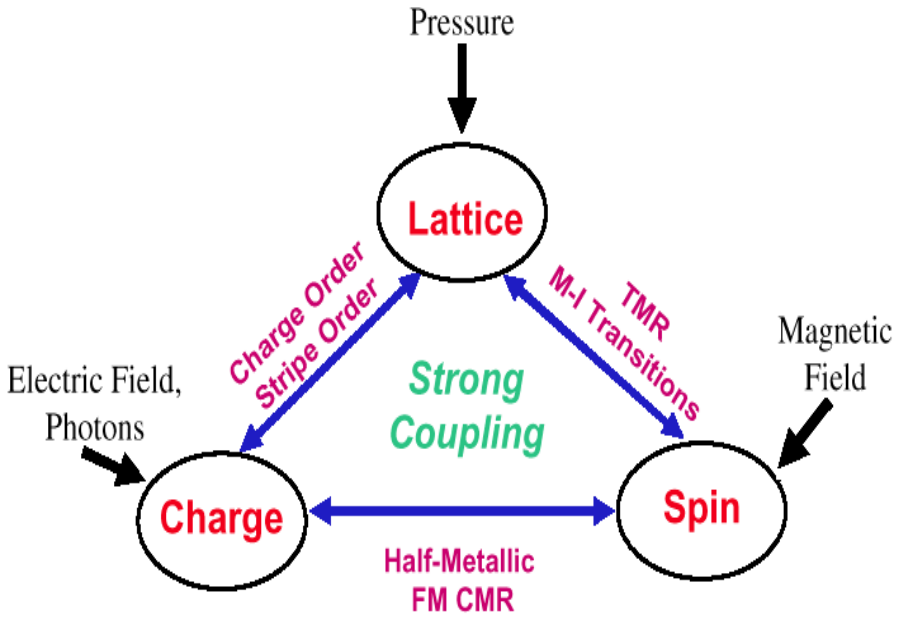


The BESSY Soft X-Ray SASE FEL

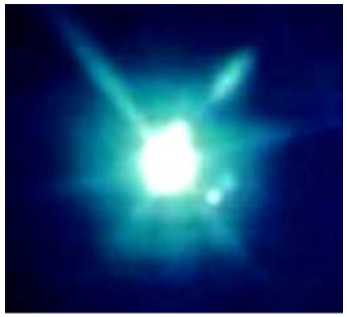
Visions of SCIENCE

Exploring the Nature of Complex Materials





Phase diagram of La_{1-x} Ca_x MnO_3 .
Data are from Cheong, Lopez, and Hwang.



The BESSY Soft X-Ray SASE FEL

Visions of SCIENCE

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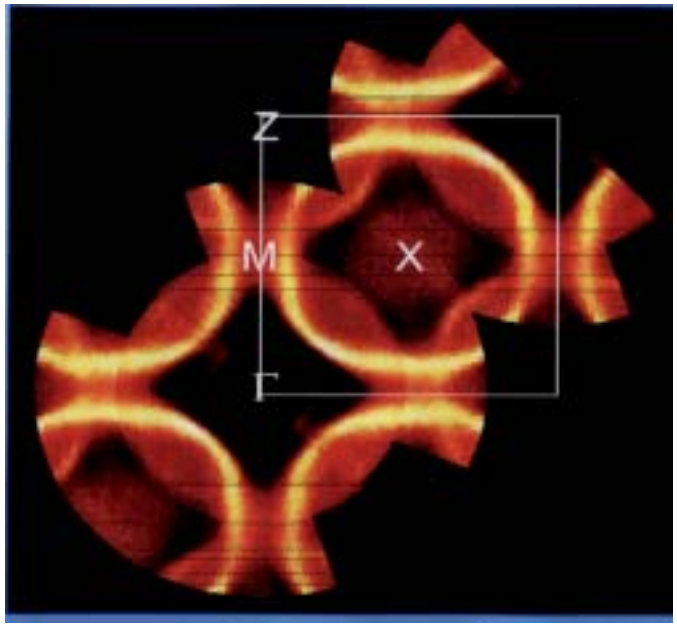
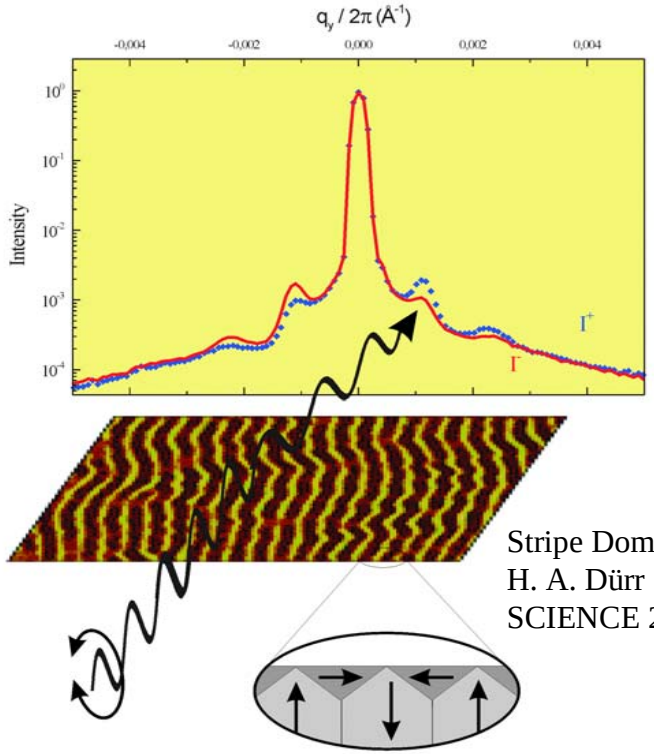


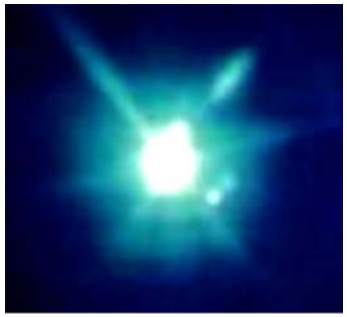
J. Fink et al. IFW Dresden

Imaging the Fermi Surface using ultra high (K) resolution angle resolved photoemission



Stripe Domains in FePd
H. A. Dürr et al.
SCIENCE 284, 2166 (1999)

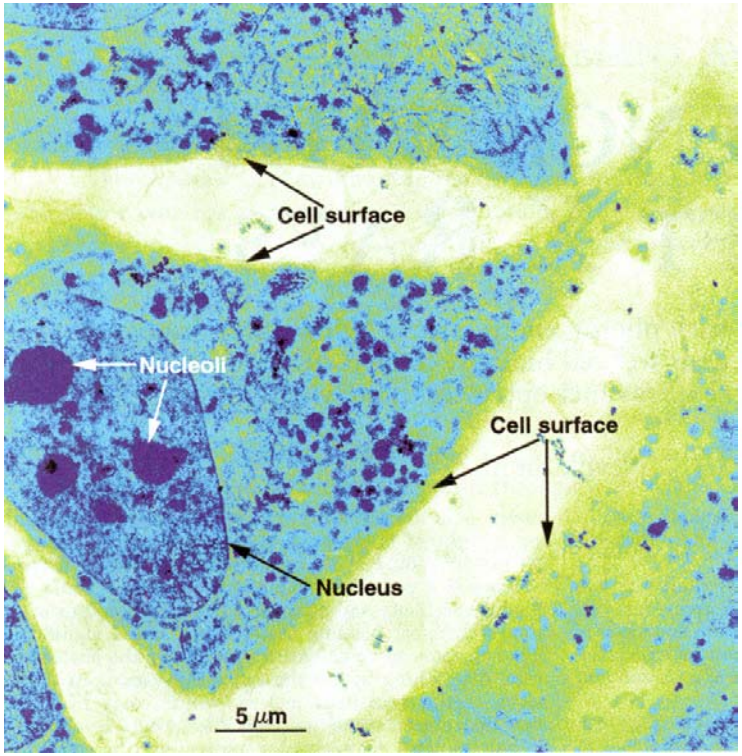
Elastic and inelastic Soft X-Ray scattering of static and dynamic charge and/or spin ordered domains



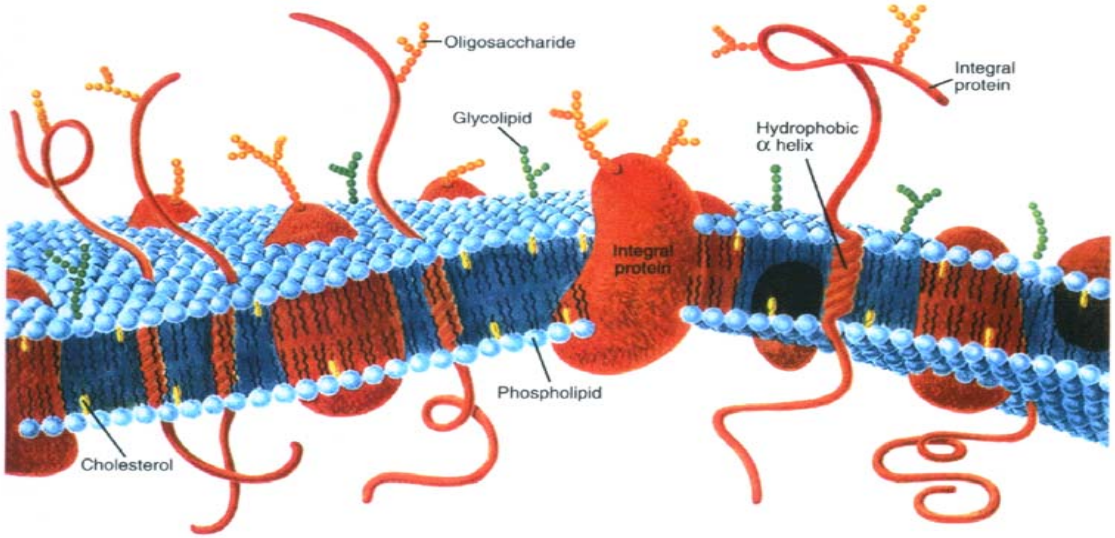
The BESSY Soft X-Ray SASE FEL

Visions of SCIENCE

Dynamics in Biological Systems (in Water)

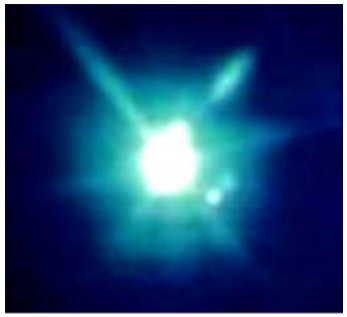


Transmission micrograph of mouse 3T3 fibroblasts, taken in the ‚water window‘
(C. Larabell ALS Berkeley)



Coherent imaging and time resolved (single pulse), chemical state sensitive microscopy of cells and membranes

Functional Cycles (photosynthesis, enzymatic reactions)
Functional Systems (ion channels, molecular motors, pumps)

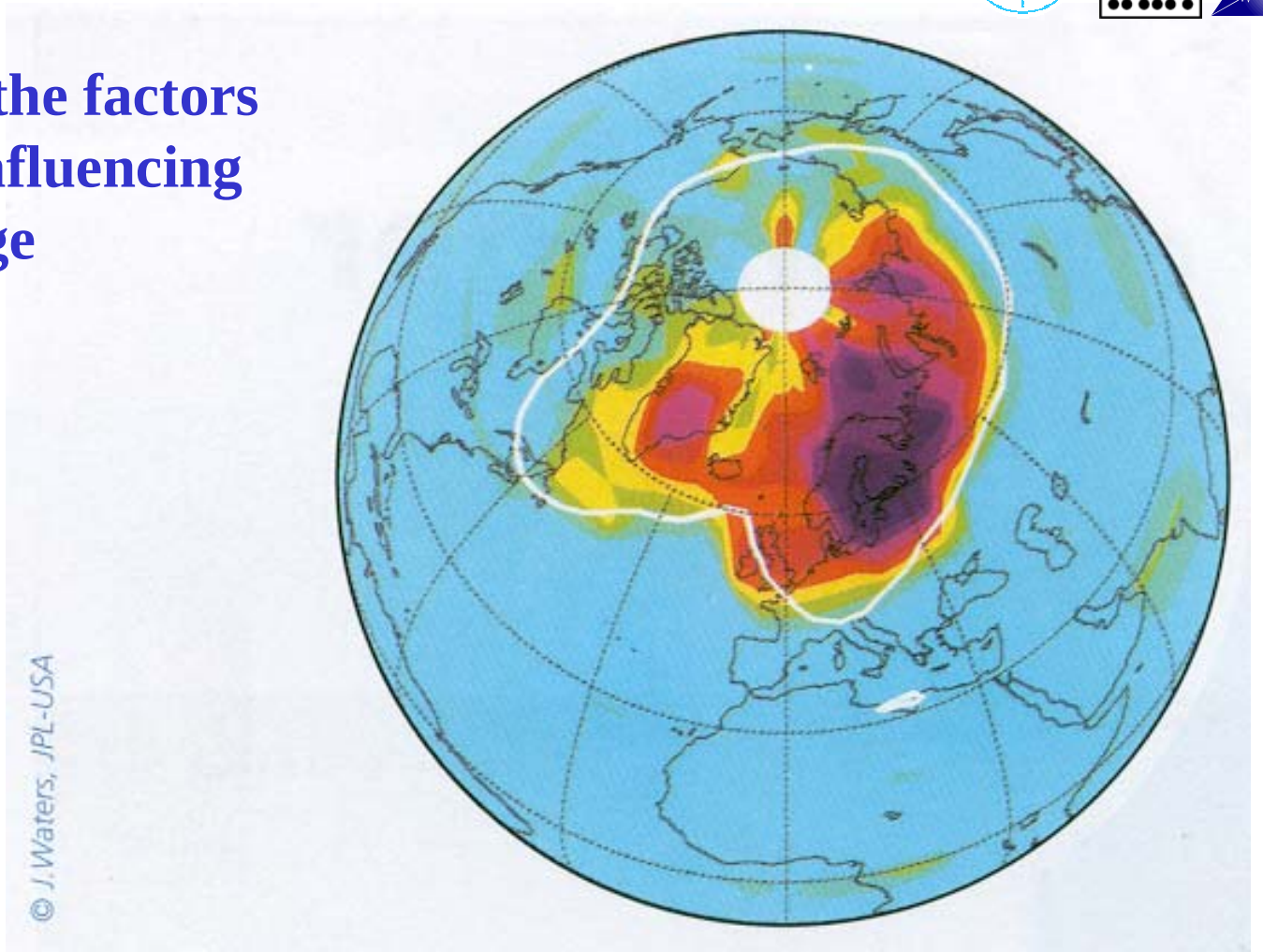


The BESSY Soft X-Ray SASE FEL

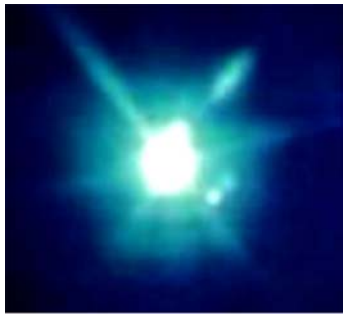
Visions of SCIENCE

Chemistry of Radicals

Understanding the factors and processes influencing the global change in climate



Ozone Hole in the Northern Hemisphere (J. Waters, JPL)

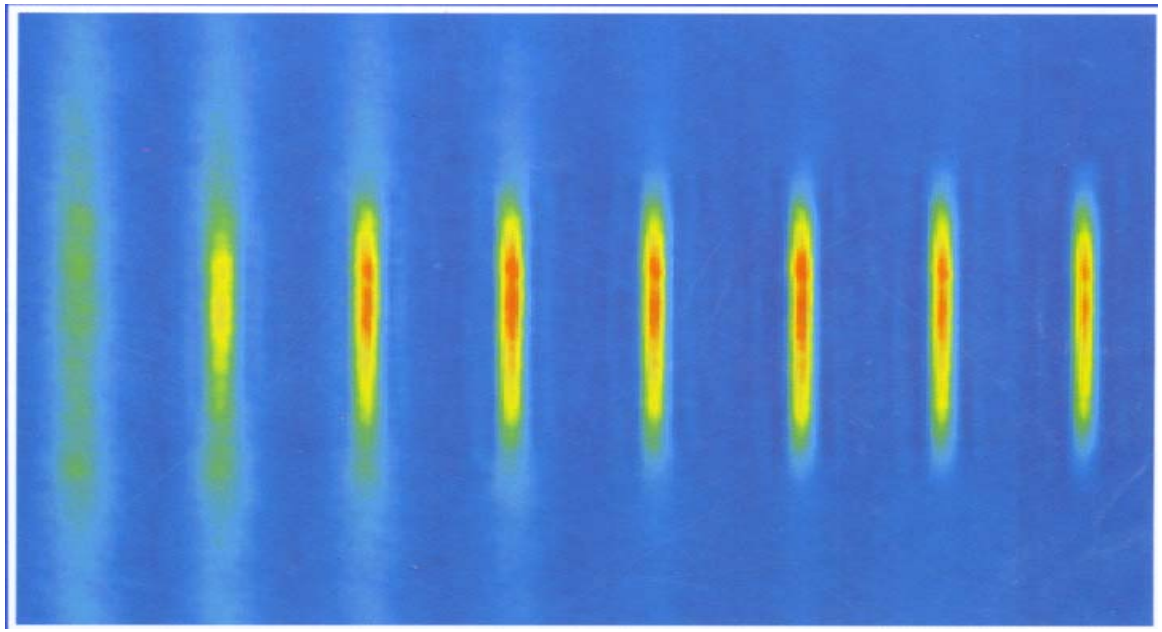


The BESSY Soft X-Ray SASE FEL

Visions of SCIENCE

Atoms, Molecules and Ions

New Fundamental Limits



Bose condensate at different temperatures
W. Ketterle, Phys. Bl. 53, 677 (1997)

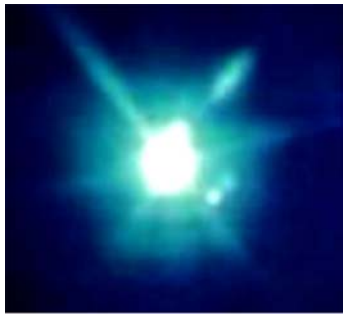
Spectroscopy on atoms and ions in traps

Quantum computing

Non-linear phenomena

Hollow atoms

Precision spectroscopy

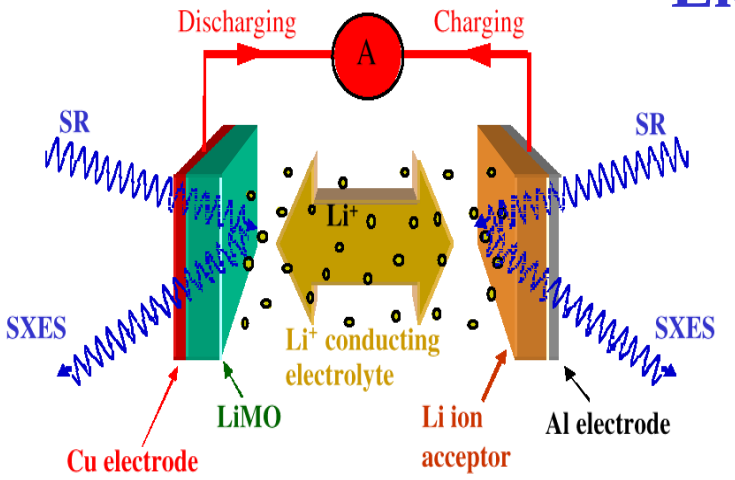


The BESSY Soft X-Ray SASE FEL

Visions of SCIENCE

Improvements in Technology

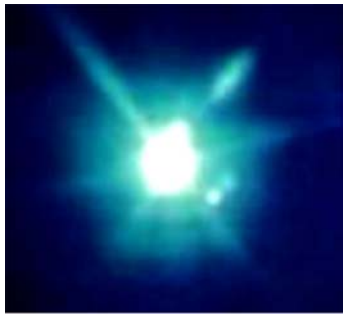
In-situ process monitoring using all photon related spectroscopies



Spectroscopy of battery electrodes under operational conditions

Electrochemistry
Corrosion
Lubrication
Catalysis

Pattern formation during a chemical reaction
G. Ertl FHI Berliin



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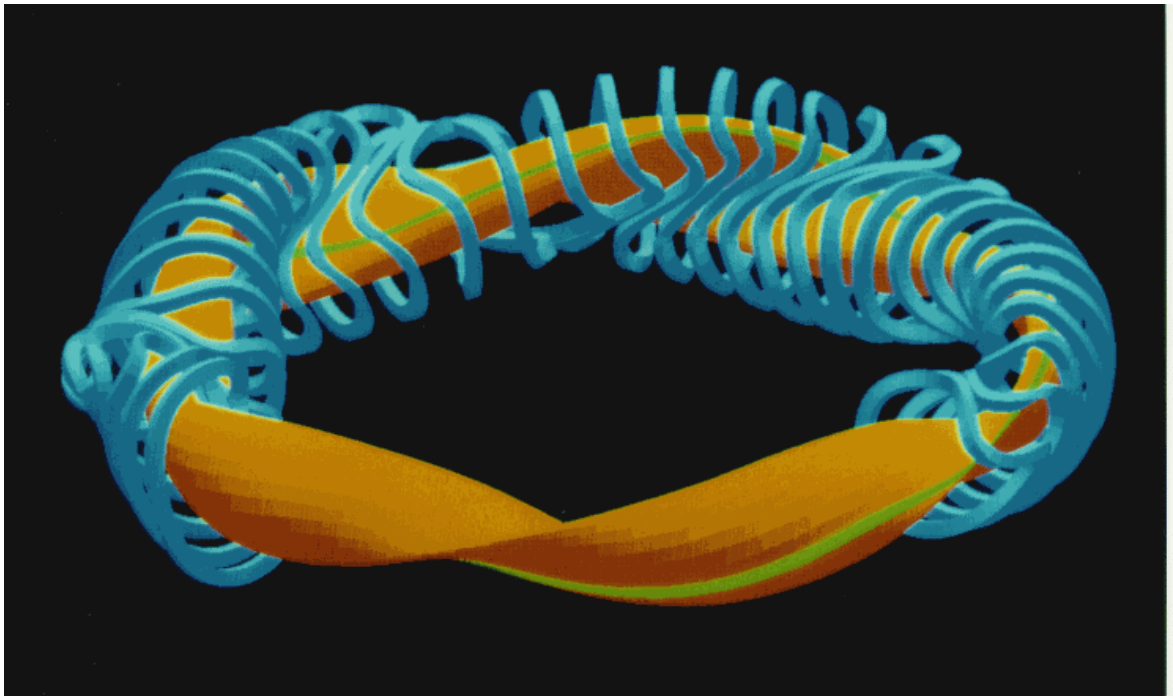
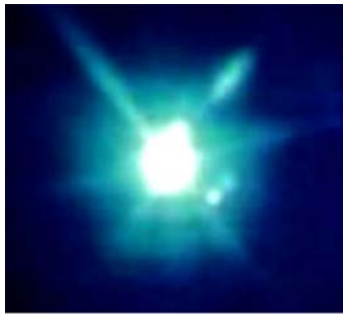
Characterization of Fusion Plasmas and Diagnostics of Fusion Reactors



Determination of cross sections and lifetimes of highly excited states of multiply charged ionic species

Model of a stellerator fusion reactor
IPP Munich and Greifswald



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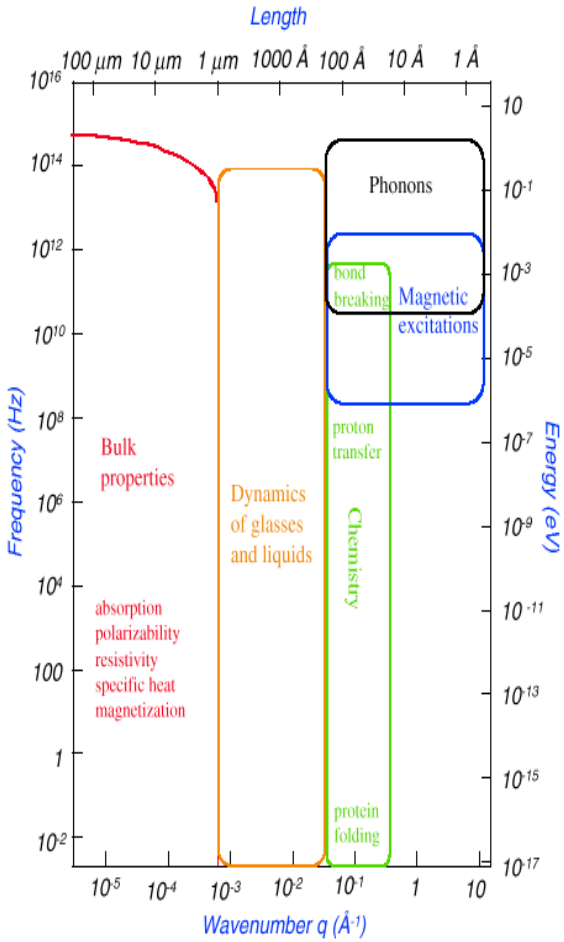
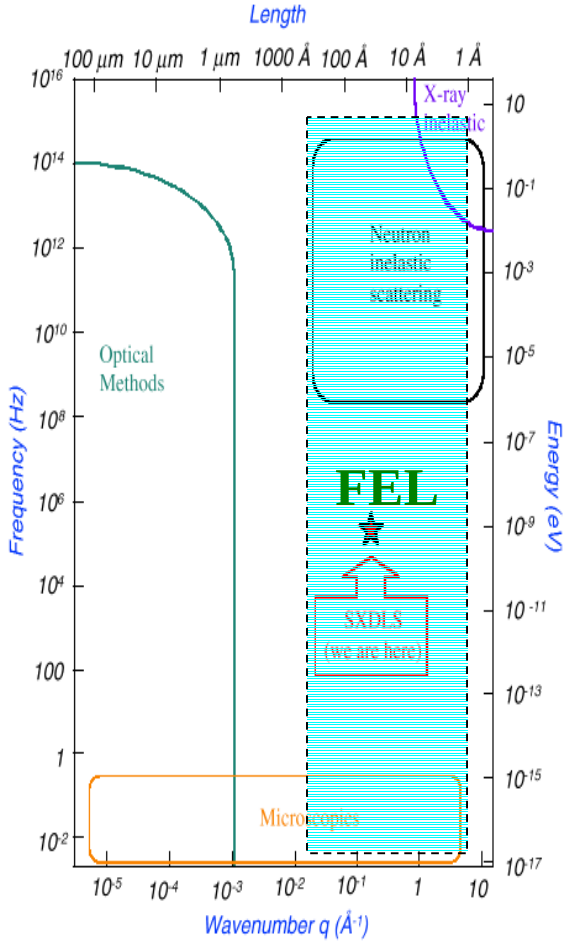
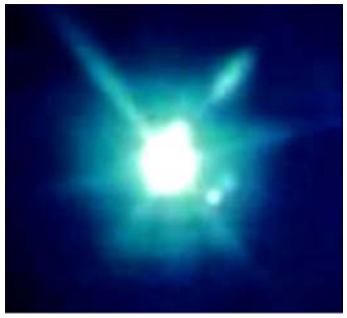
Interference pattern of a 25µm pinhole taken with 266 eV photons

S. Eisebitt et al. IFF Jülich

Scattering of Coherent Soft X-Ray Photons







The BESSY Soft X-Ray SASE FEL

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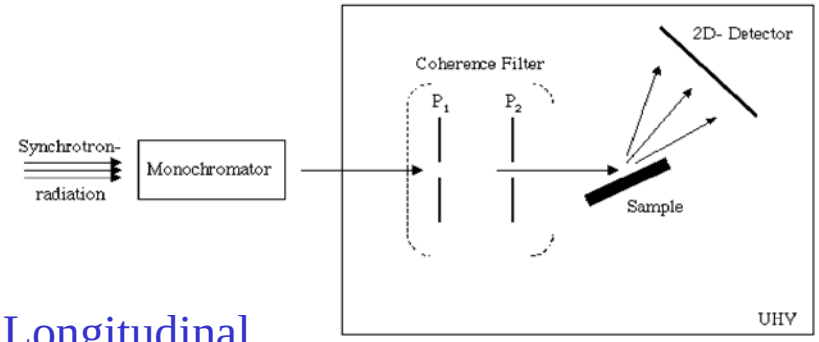
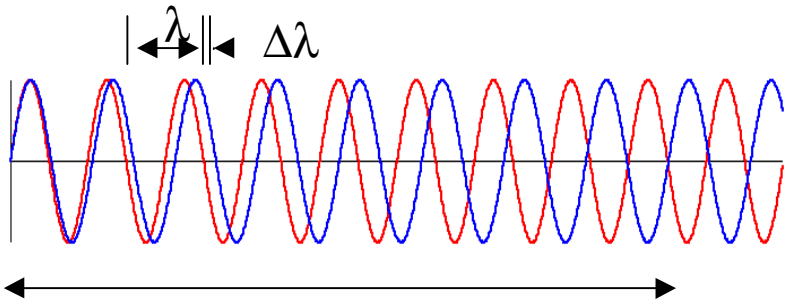
Scattering of Coherent Soft X-Ray Photons

Experimental Setup

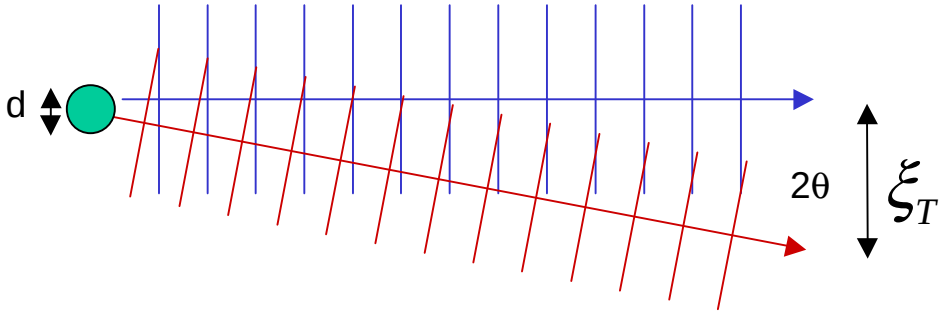


Longitudinal (temporal) coherence

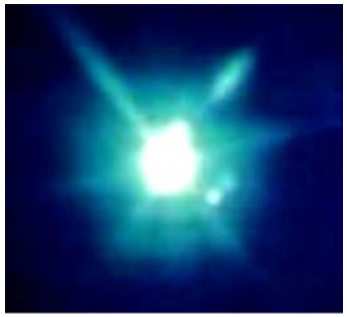
Lateral (spatial) coherence



$$\xi_L = \frac{\lambda^2}{2\Delta\lambda}$$



$$d \cdot \theta = \lambda / 2\pi$$



The BESSY Soft X-Ray SASE FEL

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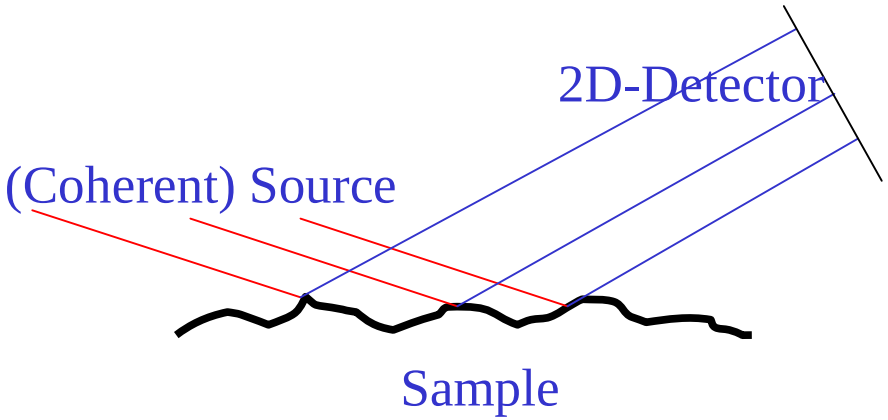
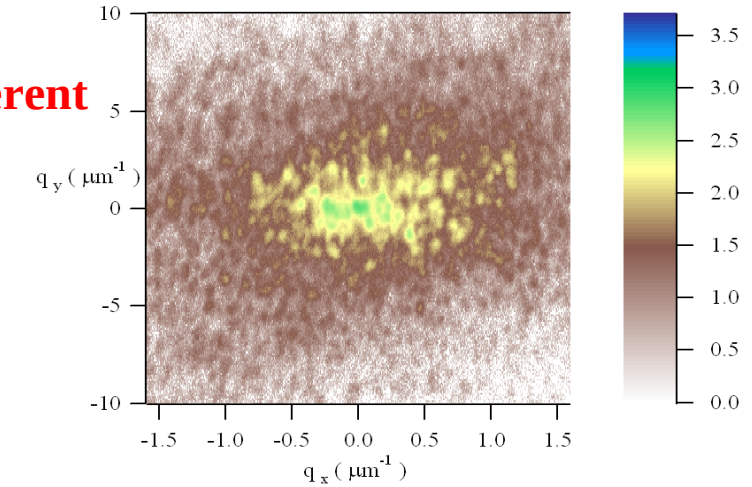
Scattering of (Coherent) Soft X-Ray Photons

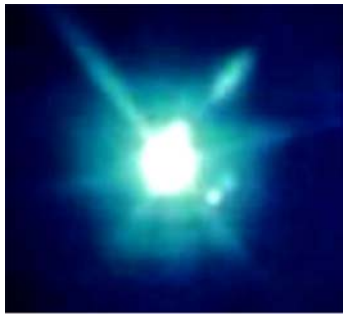


Observation of interference (SPECKLE)
Holografy without reference wave

Incoherent

Coherent





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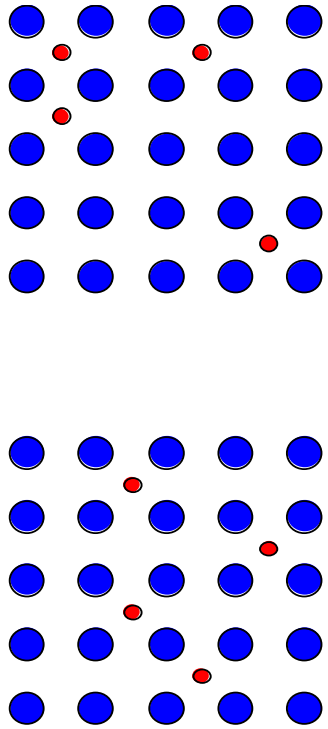
Scattering of Coherent Soft X-Ray Photons

Sensitive to the individual configuration
beyond statistical information

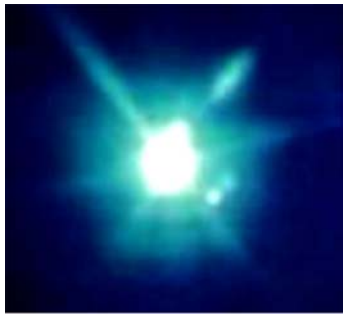
Spatial Domain
• Reconstruction, Size Information

Temporal Domain
• Finger-Print ===> Dynamics

General properties
• resonant → element selective
• photon-in photon-out
• combination of spectroscopy and scattering



Same lattice periodicity
identical mean deviation
But different individual configuration



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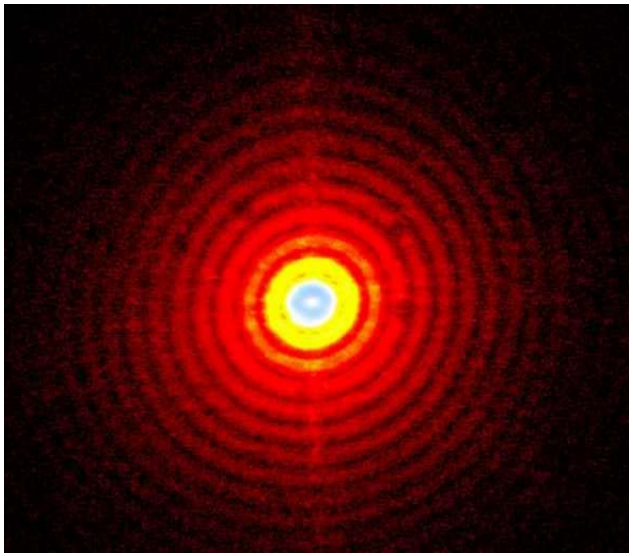
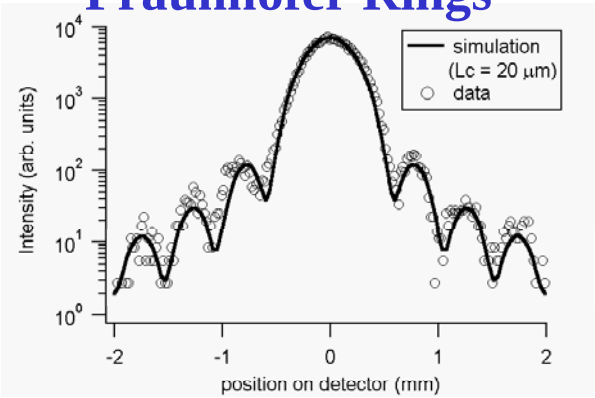
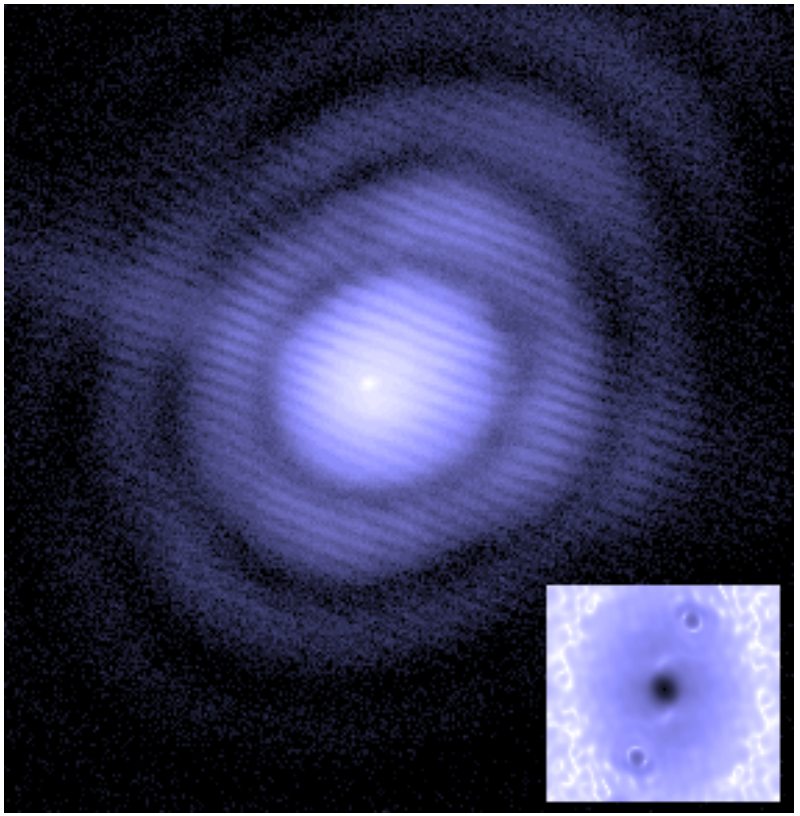
Determination of the Degree of Coherence



266 eV

Fraunhofer Rings





400 eV

Young's Double-Slit

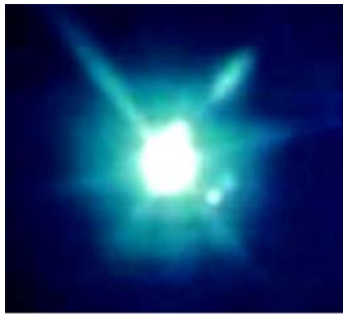


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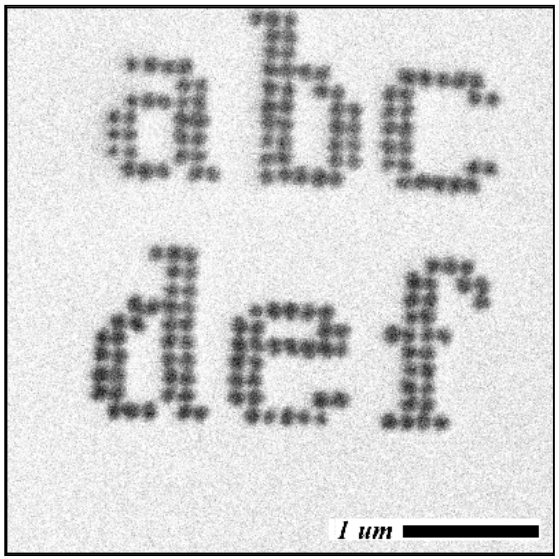
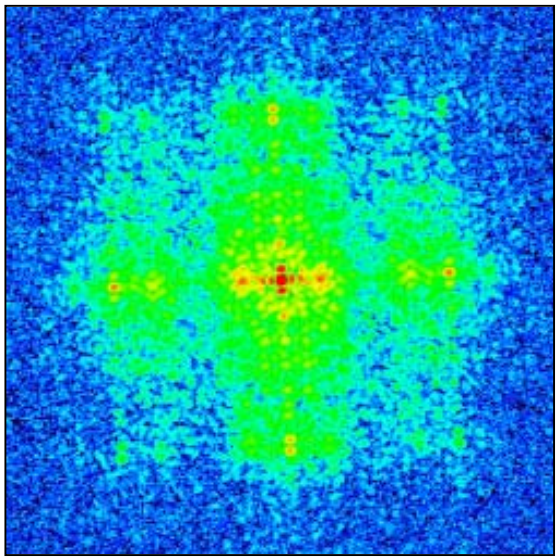
Image Reconstruction in Coherent Scattering

SEM micrograph

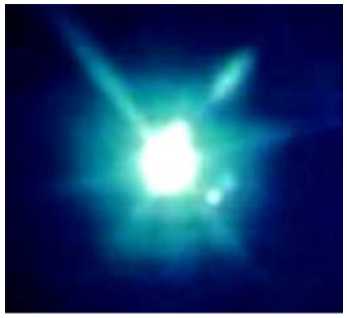


coherent scattering pattern



reconstructed image

J. Miao et al., Nature **400**, 342 (1999)



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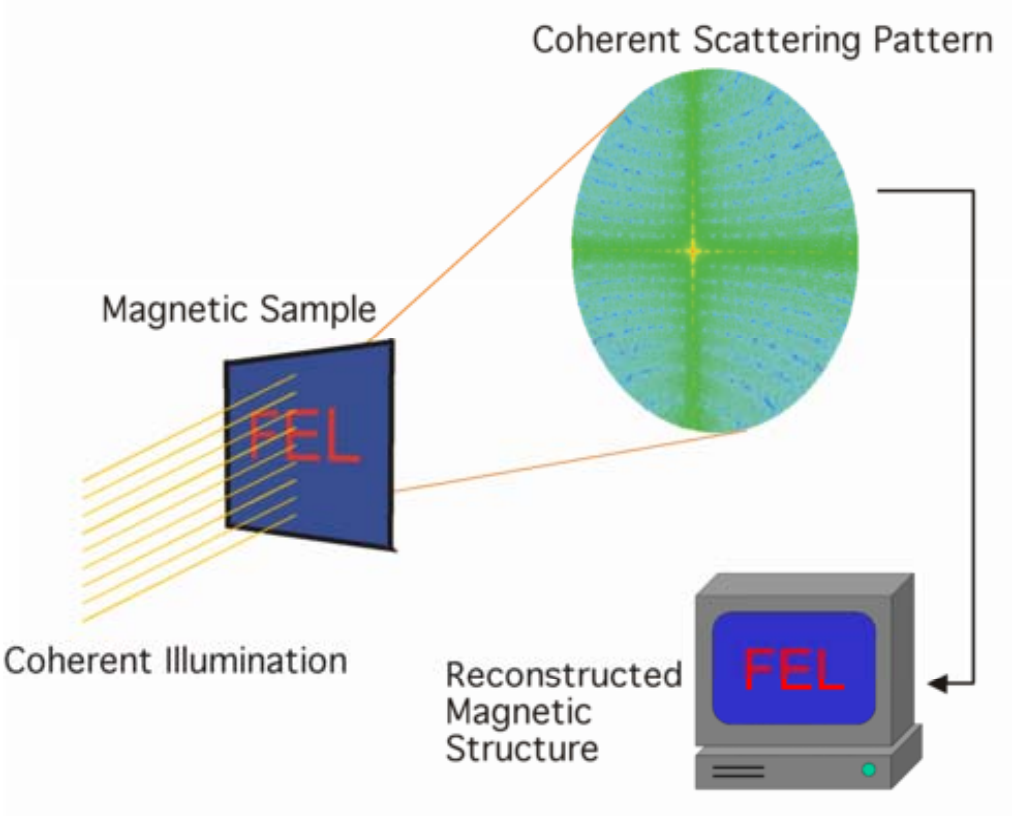
Coherent Scattering and Time resolved Imaging



Life Sciences

Magnetism

Materials Sciences

Process Monitoring