Why Do We Need the Ultrahigh (Soft) X-ray Brightness?

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Some wisdom from Larry Sorenson:

To study a coherently driven system, you can use an incoherent probe.

To study an incoherently driven system, you need a coherent probe.

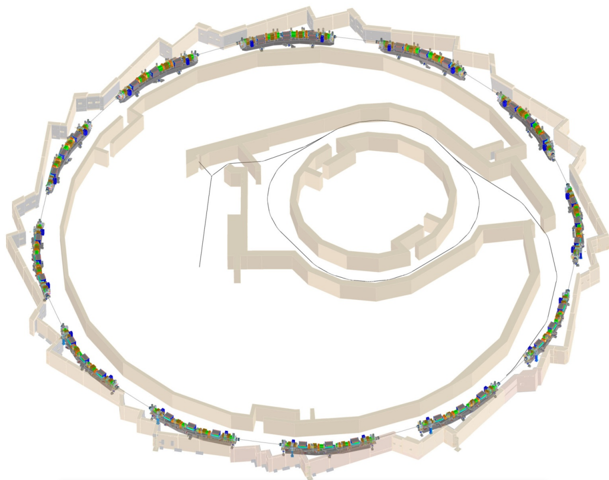
I would edit that:

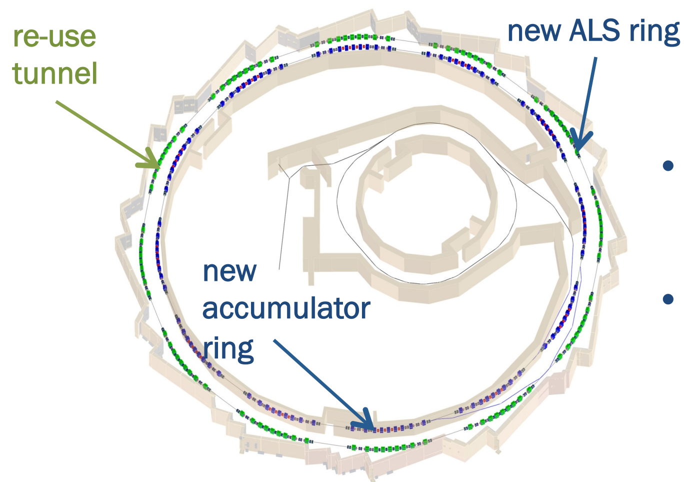
For a system that is homogeneous in space and time, a spatially incoherent probe suffices.

For a system that is heterogeneous in space and time, a spatially coherent probe is essential.

At ALS, just 1% of the photons are 'useful' in probing heterogeneous systems and devices.

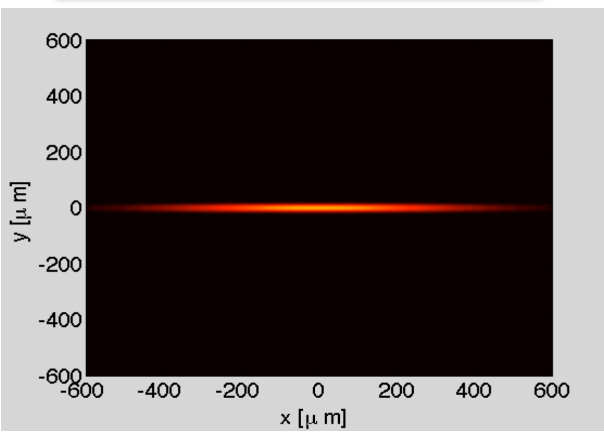
Advanced Light Source Upgrade

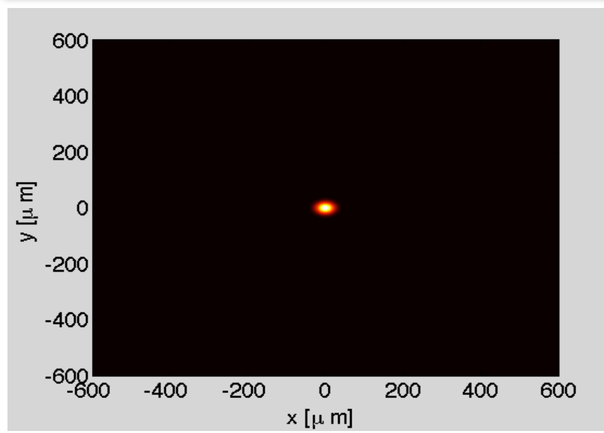




- New storage ring based on multi-bend achromat lattice
- Re-use building and ALS infrastructure

ALS Today → **Diffraction-Limited ALS (ALS-II)**

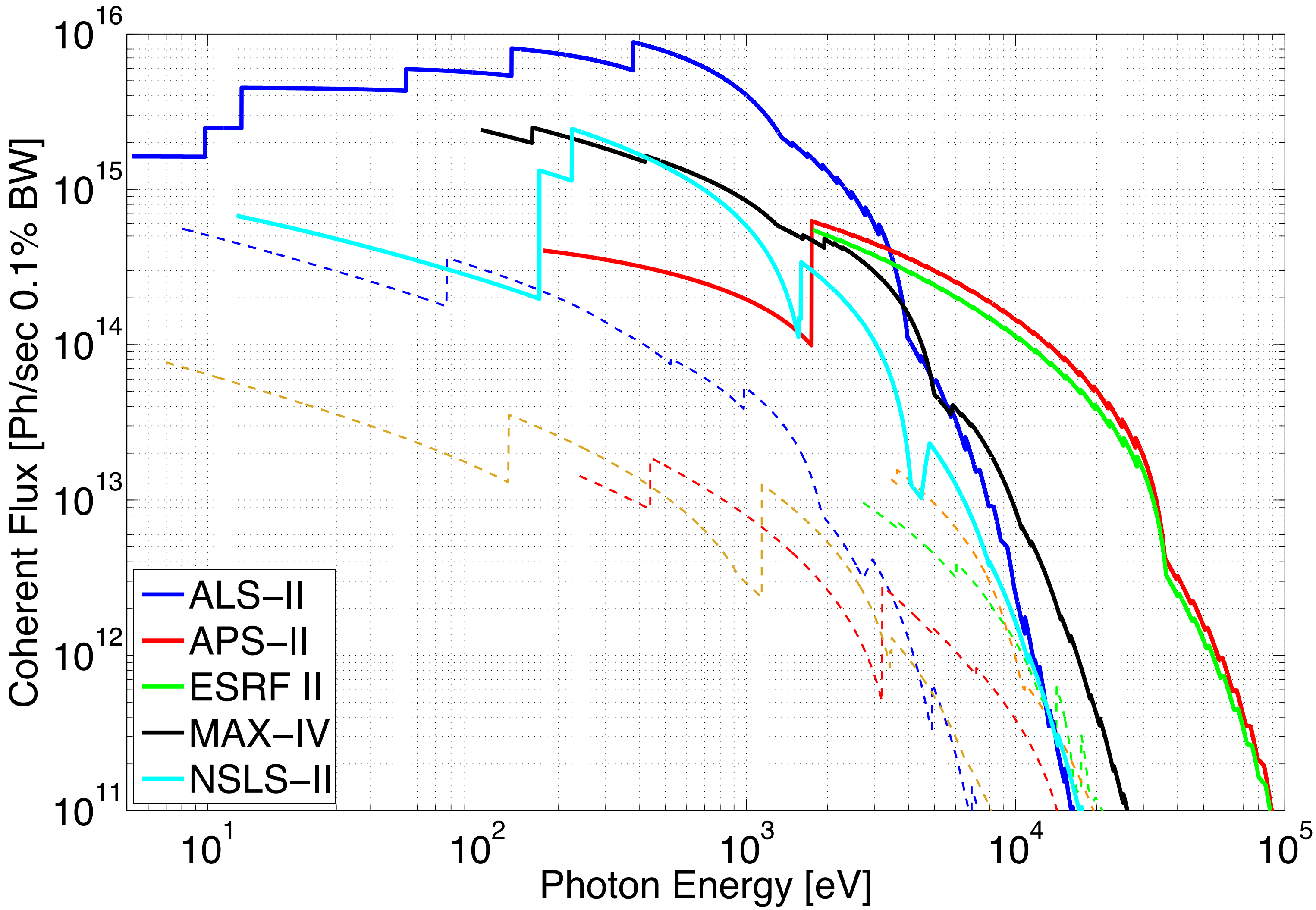




Highly coherent soft x-ray beams will enable revolutionary approaches to study heterogeneous materials and devices.

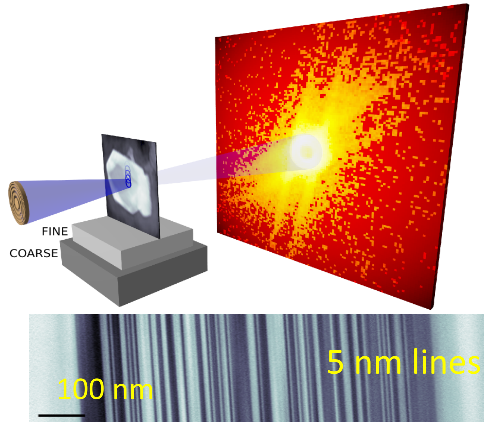
Advanced Light Source upgrade will be 100x brighter than ALS today

It's All About Coherent Flux . . .

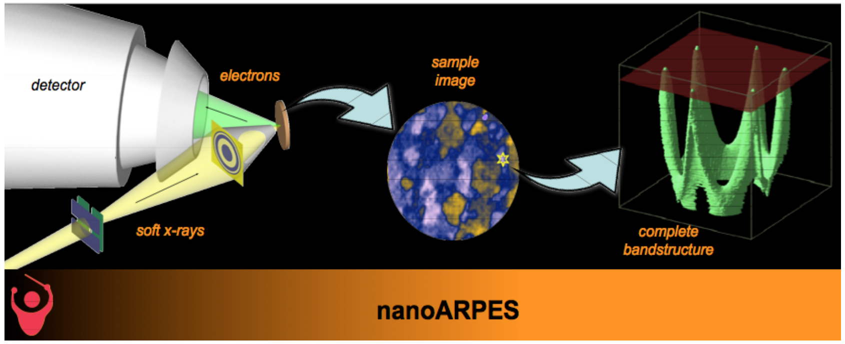


The Toolbox of Ultrahigh Brightness Storage Rings

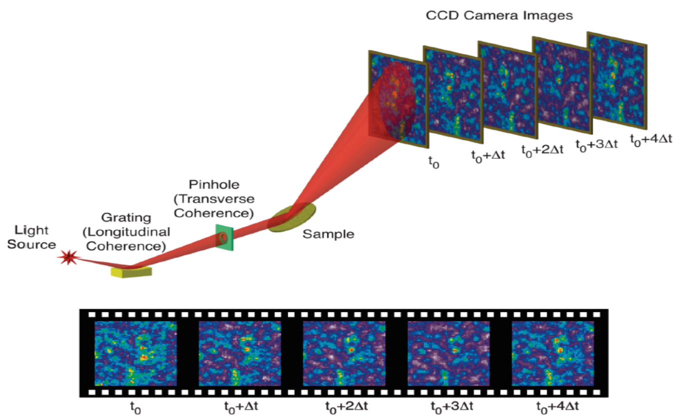
Use coherent x-rays to probe spatial and temporal heterogeneity . . .



Wavelength scale imaging

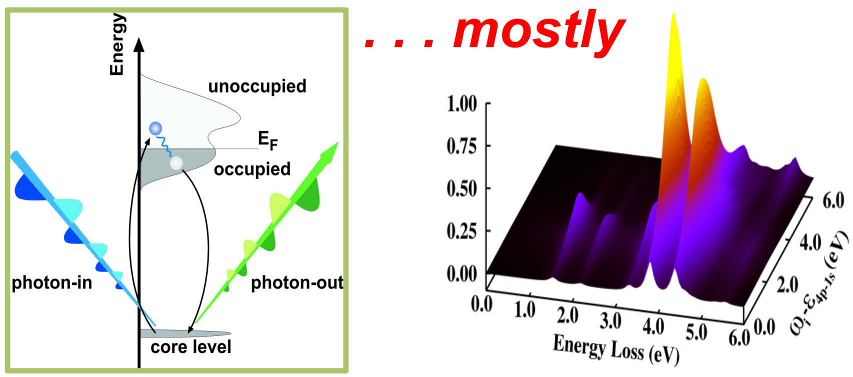


Diverse spectro-microscopies and environments



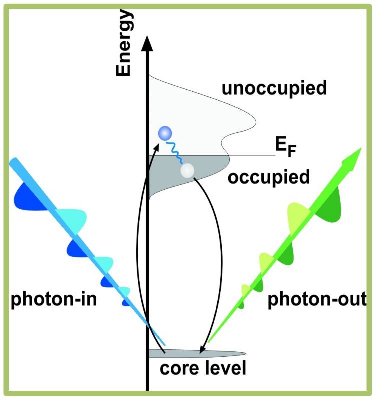
Nanometer – (sub)nanosecond kinetics

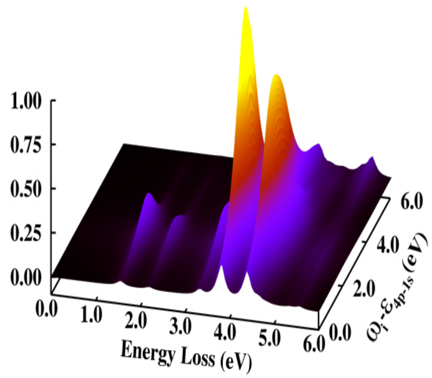
. . . mostly



Coupled excitations in complex materials

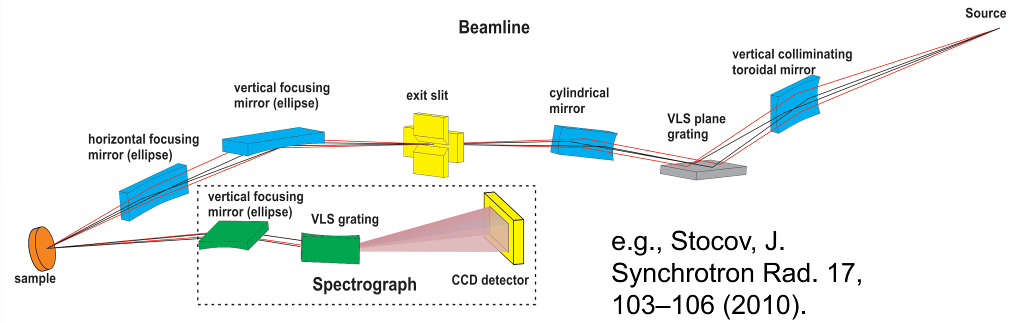
RIXS: The Smoking Gun for the Mechanism of HTSC





- Probes two particle correlations, $\mathbf{S}(\mathbf{q},\omega)$
- Bulk, interfaces, small samples
- Immune to external fields
- Broad energy range and resonant interaction to probe diverse excitations
- Soft x-rays have enough to probe the first Brillouin zone
- But this is a painfully low signal expt. . .

But to solve HTSC we need energy resolution of k_BT_c ~ 1 meV!



e.g., Stocov, J. Synchrotron Rad. 17, 103–106 (2010).

The round beam of a DLSR will enable this dispersive approach and enable ARPES-like resolution with RIXS.

Sample damage and increased BW from the pulsed source will limit FELs in this application (but pump-probe RIXS is very important)

Intrinsic Heterogeneity in Complex Oxides
nanoARPES, nanoRIXS(?), XPCS

Opportunity

- Strongly correlated electron materials exhibit many potentially useful properties.
- Control intrinsic inhomogeneity to optimize and control many remarkable properties.
- Improving critical properties of high-temperature superconductors could transform energy generation, storage, and transmission.

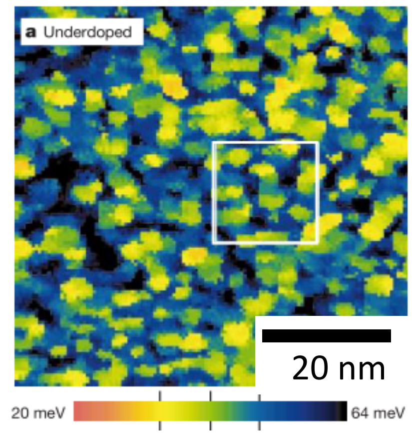
Challenge

- Understanding electronic inhomogeneity requires spectroscopic probes with 10 - 50 nm resolution.
- Current sources do not allow study on the relevant length scale.

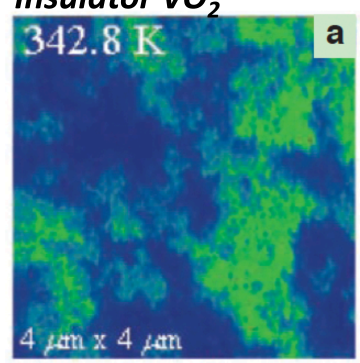
ALS-II Strengths

- nanoARPES: probe correlated electronic states on a scale less than the inhomogeneity
- nanoRIXS: probe q-dependent coupled excitations to directly understand key microscopic interactions
- XPCS: to probe thermal driven fluctuations with nanometer-nanosecond resolution

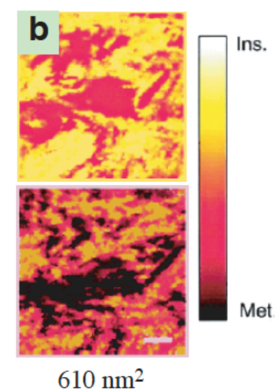
Local Variation of Superconducting Gap in Copper-Oxide Superconductor



Metal-Insulator Transition in Mott Insulator VO_2

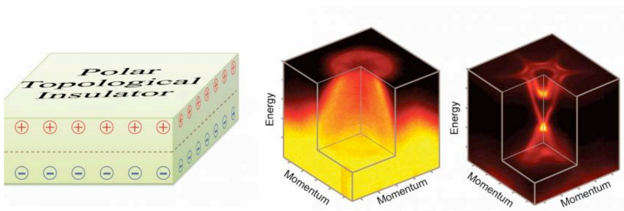


CMR Oxide (La,Ca)MnO_3



Low Power Electronics with Topological Spin Textures
Spectro-microscopy, XPCS

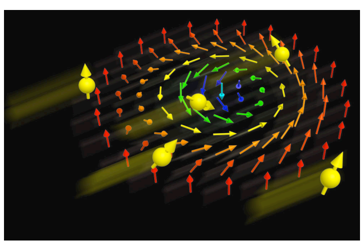
Topological Insulators

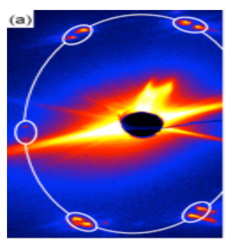


p-n junction with a topological insulator

Y.L. Chen et al, Nat. Phys, 9, 704–708 (2013)

Topological Skyrmions





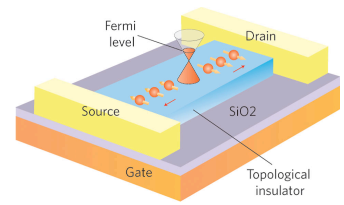
Rotating skyrmion lattices

(M. Langner, S. Roy, ALS)

Need to probe the nanometer/sub-nanosecond structure and dynamics of topological spin textures.

Weakly coupled to the lattice

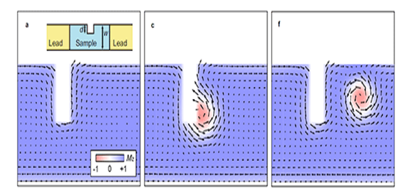
- - ***very low power dissipation***



Xiu, F. et al. Nature Nanotech. 6, 216–221 (2011).

Controlled with current, fields

- - ***spin-based electronic devices***

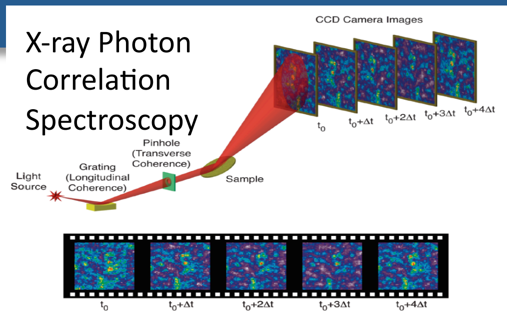


Iwasaki, Nature Nanotechnology 8, 742–747 (2013).

Textures move and interact in space and time

- - ***need to understand nanoscale spin structure and spin dynamics***

Nano-Kinetics with SXR Contrast



Challenge

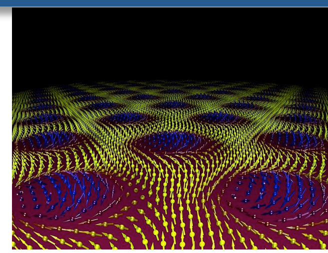
Probe chemical, magnetic, and structural fluctuations with nm-ns resolution

Opportunity

- Accessible XPCS time scale proportional to (coherent flux)^2
- 100-fold increased brightness improves time resolution by 10^4

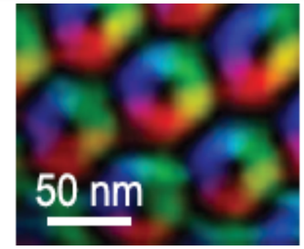
DLSRs enable ns-resolution studies of nm-scale fluctuations

- Reaction-diffusion
- Self-assembly
- Domain wall motion
- Complex order parameters



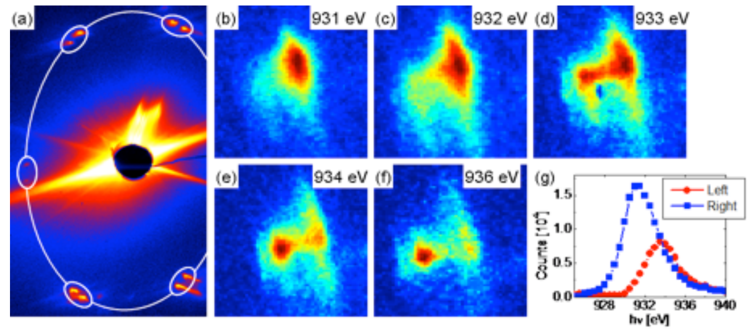
Skyrmions

topological, chiral magnetic defect: strange dynamics, proposed for information storage.



Skyrmion lattice

*Seki et. al. Science **336**, 198 (2012).*



Skyrmions @ ALS in Cu_2OSeO_3

(M. Langner, S. Roy, ALS)

Two rotated skyrmion lattices associated different Cu atoms

Time required to probe skyrmion fluctuations on various time scales:

source	beamline	Count/s-speckle	Δt = 1 ms	1 μs	1 ns	10 ps
ALS	BL12.0	5	.05 hrs	50 hrs	50,000 hrs	
ALS	COSMIC	50		0.5 hrs	500 hrs	
NSLS-II	CSX	500			5 hrs	
ALS-II	COSMIC	5000			0.05 hrs	5 hrs