Looking Forward to NSLS-II and Future Capabilities

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Director, Experimental Facilities Division
NSLS-II
Workshop on Applications in Glass Research
April 6, 2009

Office of Science
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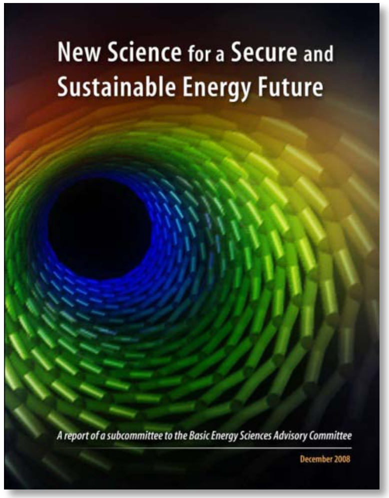
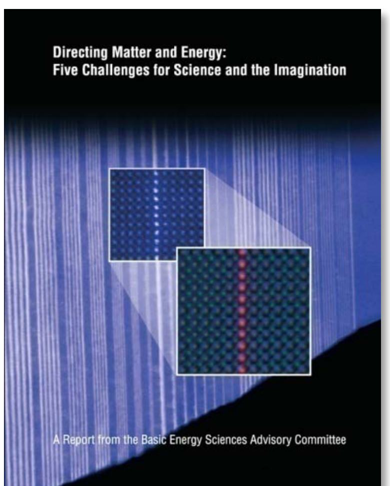
NSLS-II: New Synchrotron Light Source Facility





- Designed to satisfy the research needs to address Grand Challenges in science and technology

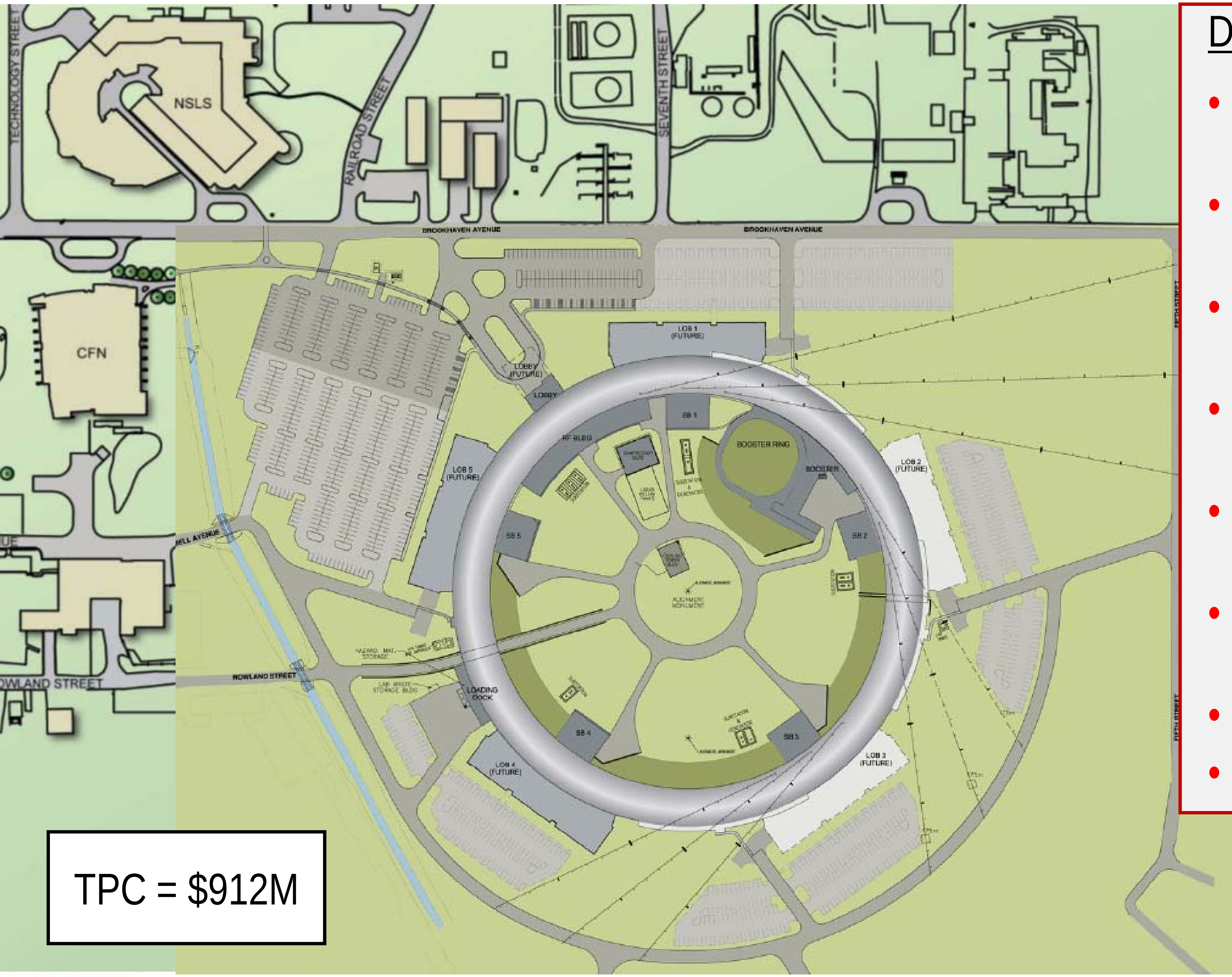
Five Grand Challenges for Basic Energy Sciences

- *How do we control material processes at the level of electrons?*
- *How do we design and perfect efficient synthesis of new forms of matter with tailored properties?*
- *How do remarkable properties of matter emerge from complex correlations and how can we control these properties?*
- *How can we master energy and information on the nanoscale to create new technologies that rival those of living things?*
- *How do we characterize and control matter away from equilibrium?*

New Science for Secure & Sustainable Energy Future:

- *High-performance materials to enable precise control of chemical change*
- *Characterization tools probing the ultrafast and the ultrasmall*
- *New understanding based on advanced theory and simulation*

NSLS-II: Optimized 3rd Generation Synchrotron Source

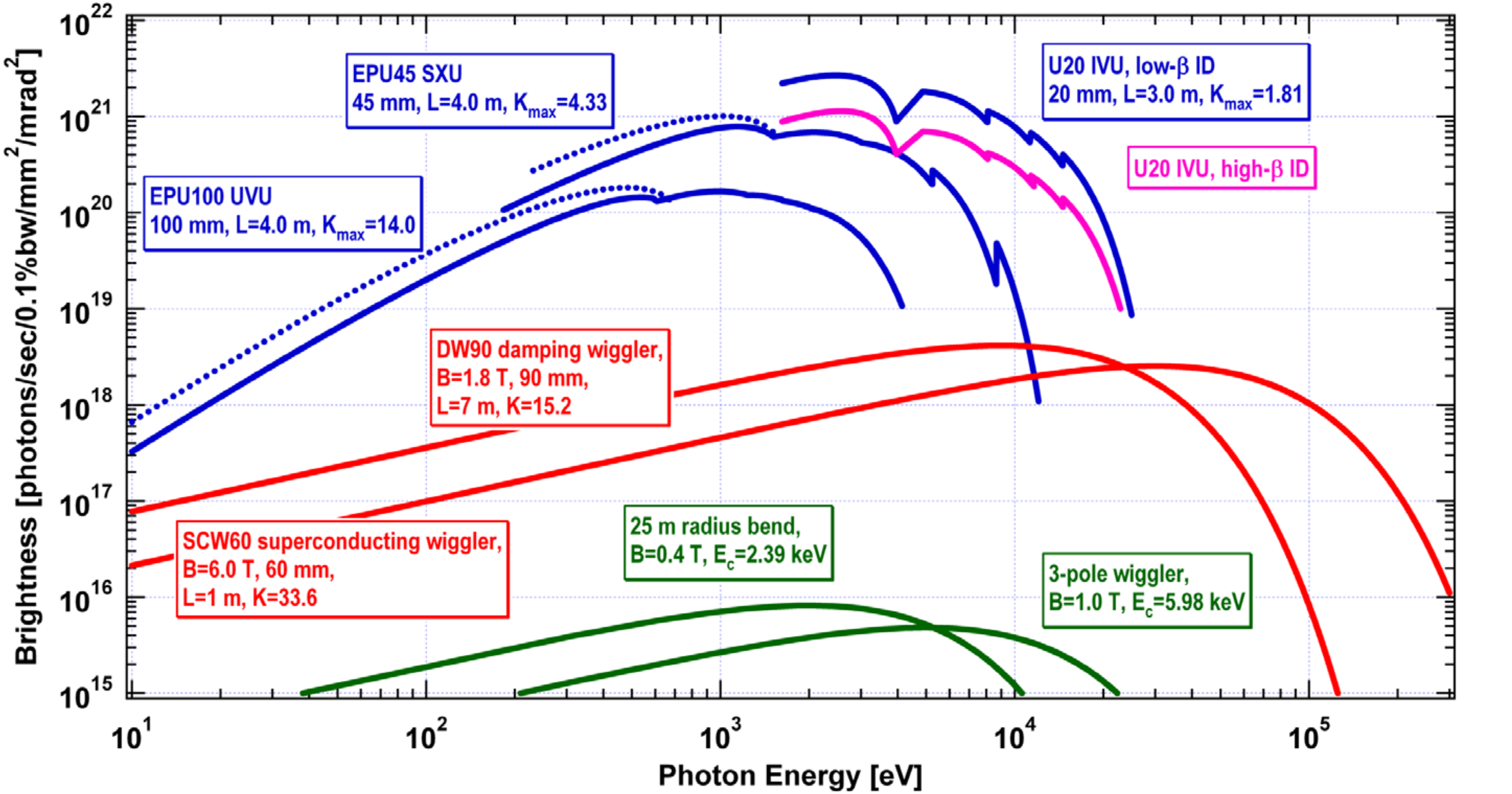


TPC = $912M

Design Features:

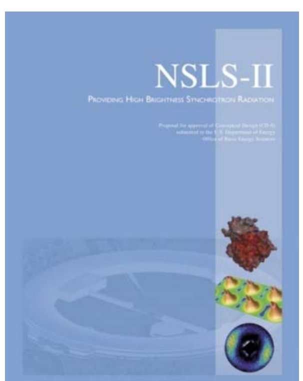
- 3 GeV, 500 mA, Circumference 791 m
- Low emittance: ε_x, ε_y= 0.6, 0.008 nm-rad
- High brightness from soft to hard x-rays
- Diffraction limited in vertical to 12 keV
- Small beam size: σ_y= 2.6 μm, σ_x= 28 μm
- Pulse length (rms) ~15 psec
- Lab & office bldg.
- Long beamlines

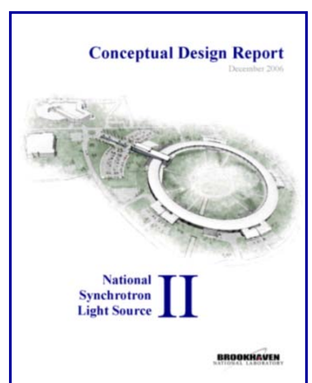
World-leading High Brightness at NSLS-II

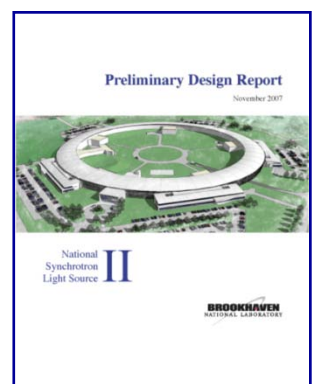


NSLS-II Key Milestones

Aug 2005	CD-0, Approve Mission Need	(Complete)
Jul 2007	CD-1, Approve Alternative Selection and Cost Range	(Complete)
Jan 2008	CD-2, Approve Performance Baseline	(Complete)
Dec 2008	CD-3, Approve Start of Construction	(Complete)
Feb 2009	Contract Award for Ring Building	(Complete)
Aug 2009	Contract Award for Storage Ring Magnets	
Mar 2010	Contract Award for Booster System	
Feb 2011	1st Pentant of Ring Building Ready for Accelerator Installation	
Feb 2012	Beneficial Occupancy of Experimental Floor	
Oct 2013	Start Accelerator Commissioning	
Jun 2014	Early Project Completion; 1st Beam to Beamlines soon afterwards	
Jun 2015	CD-4, Approve Start of Operations	

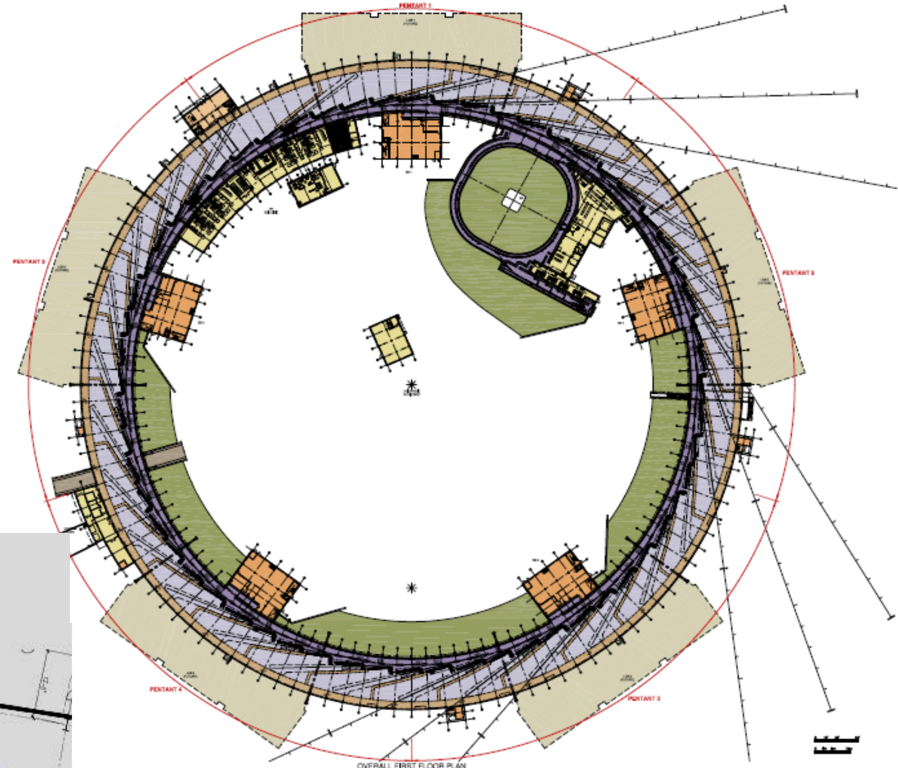




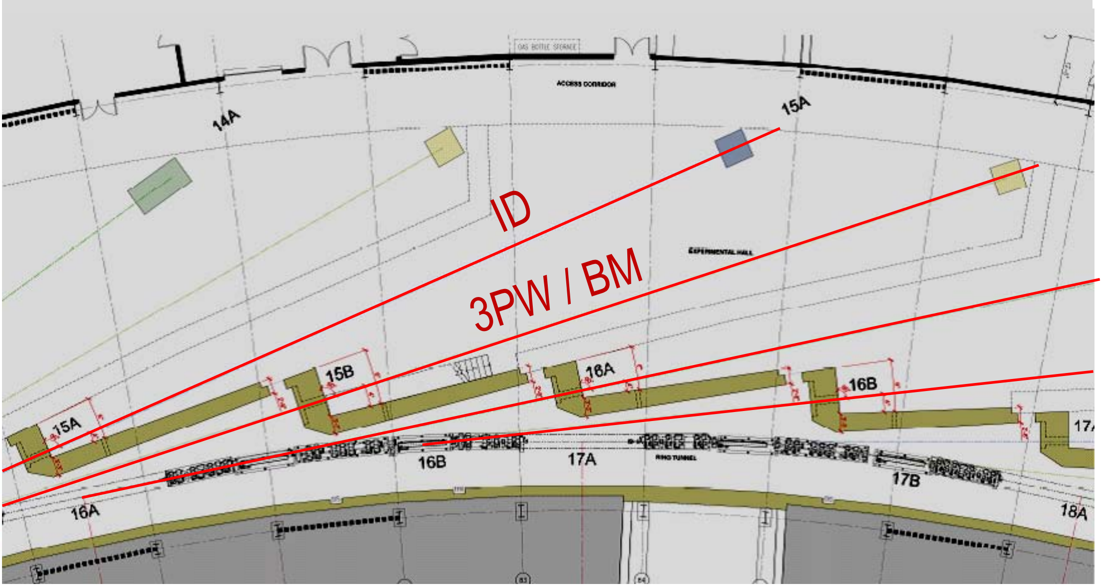


NSLS-II Experimental Facility Capacity

- 27 straight sections for insertion device beamlines
- 31 BM and/or 3PW beamlines
- at least 58 beamlines, plus canted IDs
- current estimate of fully built-out facility: 78 full-time equivalent beamlines



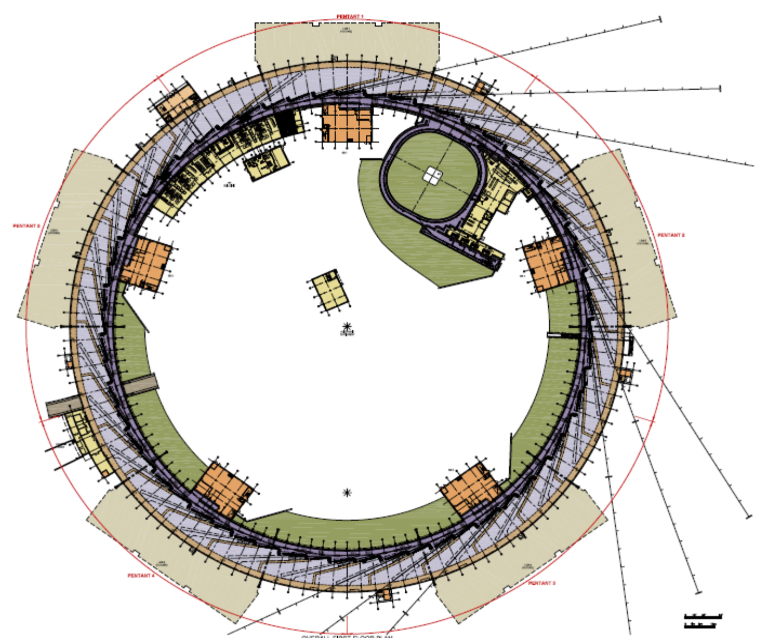
Typical NSLS-II Sector



NSLS-II Beamline Build-out Timeline (estimate)

FUNDING	BEAMLINES
BES – Project	6 insertion device beamlines in base project scope
BES – Early Operations	~ 20 bending magnet beamlines transferred from NSLS to NSLS-II, using NSLS-II early operations funding
BES – MIE	~ 16 insertion device beamlines
Non-BES	Life Science beamlines and other non-BES missions

~ 43 beam ports operating by 2017
→ 75% of capacity



Beamline Development Process

All beamlines to be developed using Beamline Advisory Teams (BATs)

- Teams formed by submitting a Letter of Interest (LOI), representing a particular user community
- LOIs reviewed by external reviewers and Experimental Facilities Advisory Committee (EFAC), and approved by NSLS-II management
- BATs work with facility to define scientific mission and technical requirements for beamline
- Work closely with facility during design, construction, commissioning, and early operations
- NSLS-II has overall responsibility for development and operation of beamlines, ensuring that they are well integrated into the facility and with missions that are consistent with the overall strategic plan of the facility
- User access will include General Users and Partner Users

1st-round Beamline and Scientific Planning Workshops

January – March, 2008

Workshop (Attendees)

- XPCS/SAXS (44)
- X-ray Spectroscopy (54)
- Powder Diffraction (52)
- Soft x-ray Scattering (34)
- Inelastic Scattering (45)
- Nanoprobe (31)
- Coherent Diffraction (33)
- Life Sciences (72)
- Mat. Sci. Eng. (95)
- Earth & Environ. Sci. (54)
- Chem. Energy Sci. (37)
- Con. Mat. & Mat. Phys. (50)
- Soft & Biomole. Mat. (60)

XPCS/SAXS

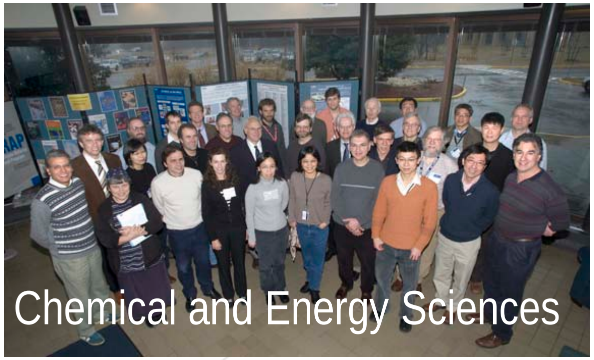
Powder

- One clear message was the advantages (scientific and technical) to be gained by appropriately combining communities with similar requirements

X-ray Spectroscopy

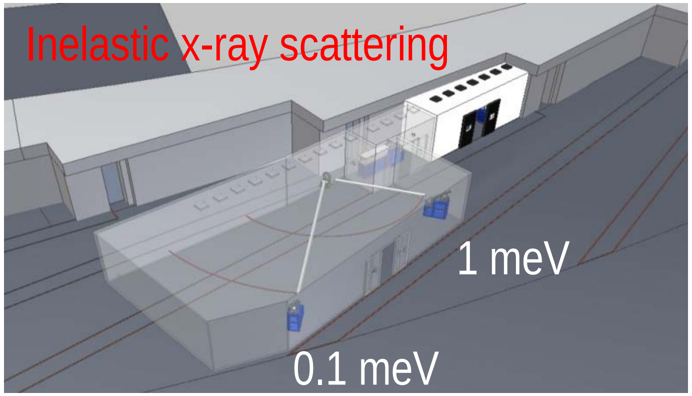
Life Sciences

Earth and Environmental Sciences

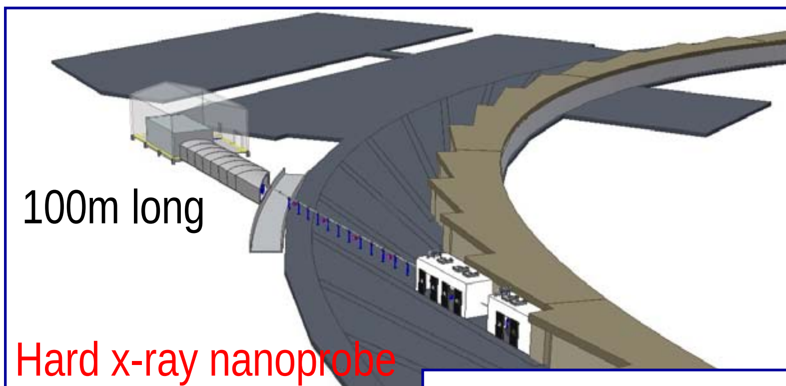


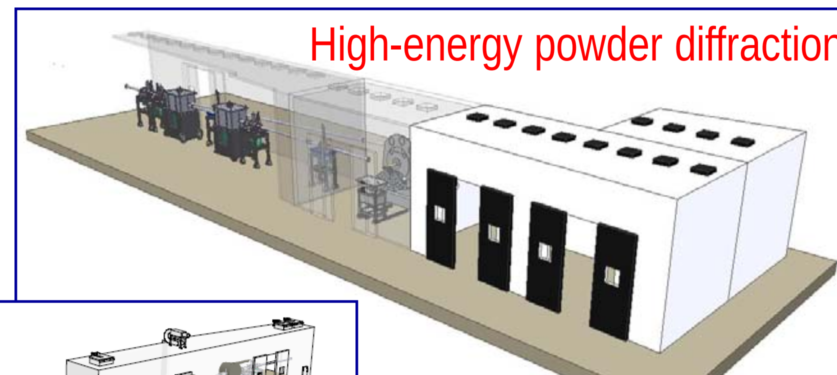
Chemical and Energy Sciences

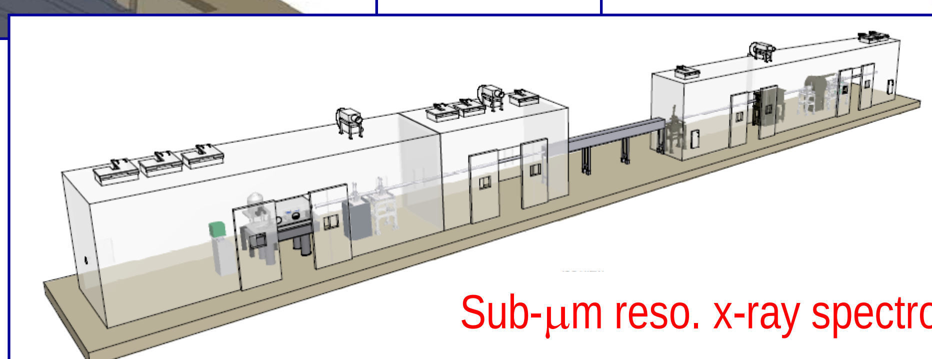
Initial Six Project Beamlines at NSLS-II



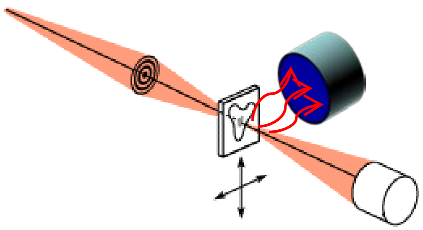
- Inelastic x-ray scattering
- Hard x-ray nanoprobe
- Coherent hard x-ray scattering
- Soft x-ray scattering/polarization
- X-ray powder diffraction
- Sub-μm resolution x-ray spectroscopy



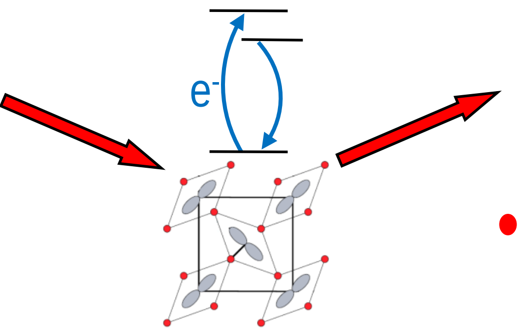




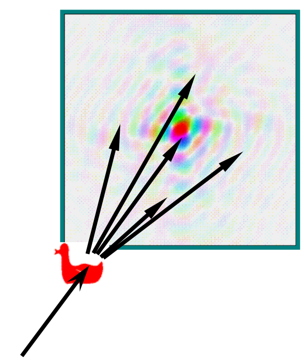
Enhanced and New Capabilities at NSLS-II



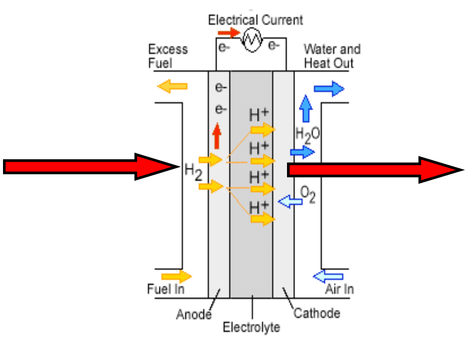
- High brightness & small source size enables development of nanometer sized x-ray beams ➔ Opens up new opportunities for structural & spectroscopic materials studies at nanoscales



- High brightness & high angular definition enables development of high energy-resolution x-rays ➔ Opens up new possibilities for structural dynamic and spectroscopic studies based on inelastic processes



- High brightness & high coherence enables coherence-based imaging capabilities ➔ Opens up new imaging modalities for structural studies of noncrystalline materials and amorphous materials



- High brightness & high flux enables a broad range of in-situ and real-time capabilities ➔ Opens up new opportunities for to study materials structure and process under realistic conditions and in functional environment (buried structures, reaction, …)

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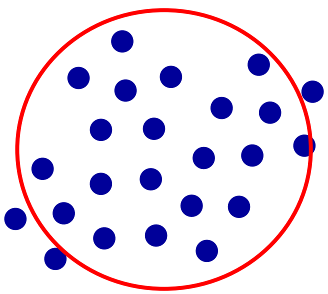
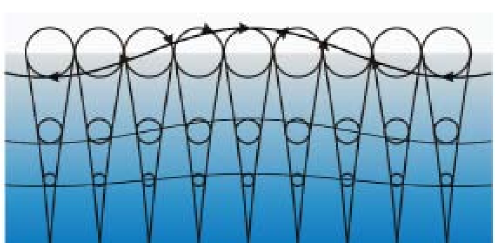
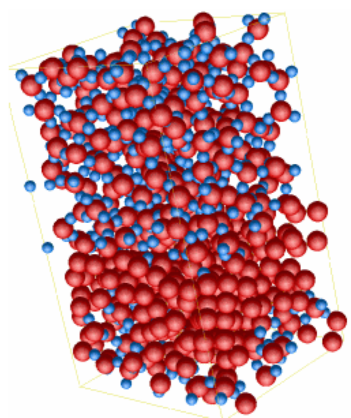
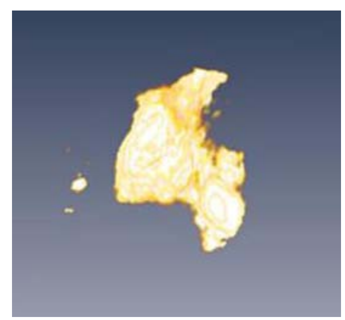
New Opportunities in Glass Materials Research at NSLS-II

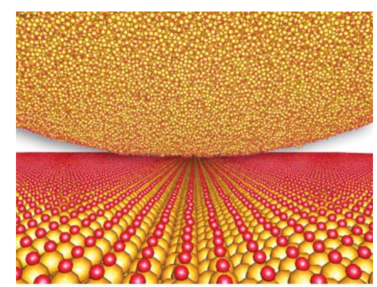




- Nanoscale glass materials engineering
- Total structures at atomic scale
- Nonequillibrium fluctuation dynamics
- Amorphous materials under extreme conditions
- Fundamental engineering physics



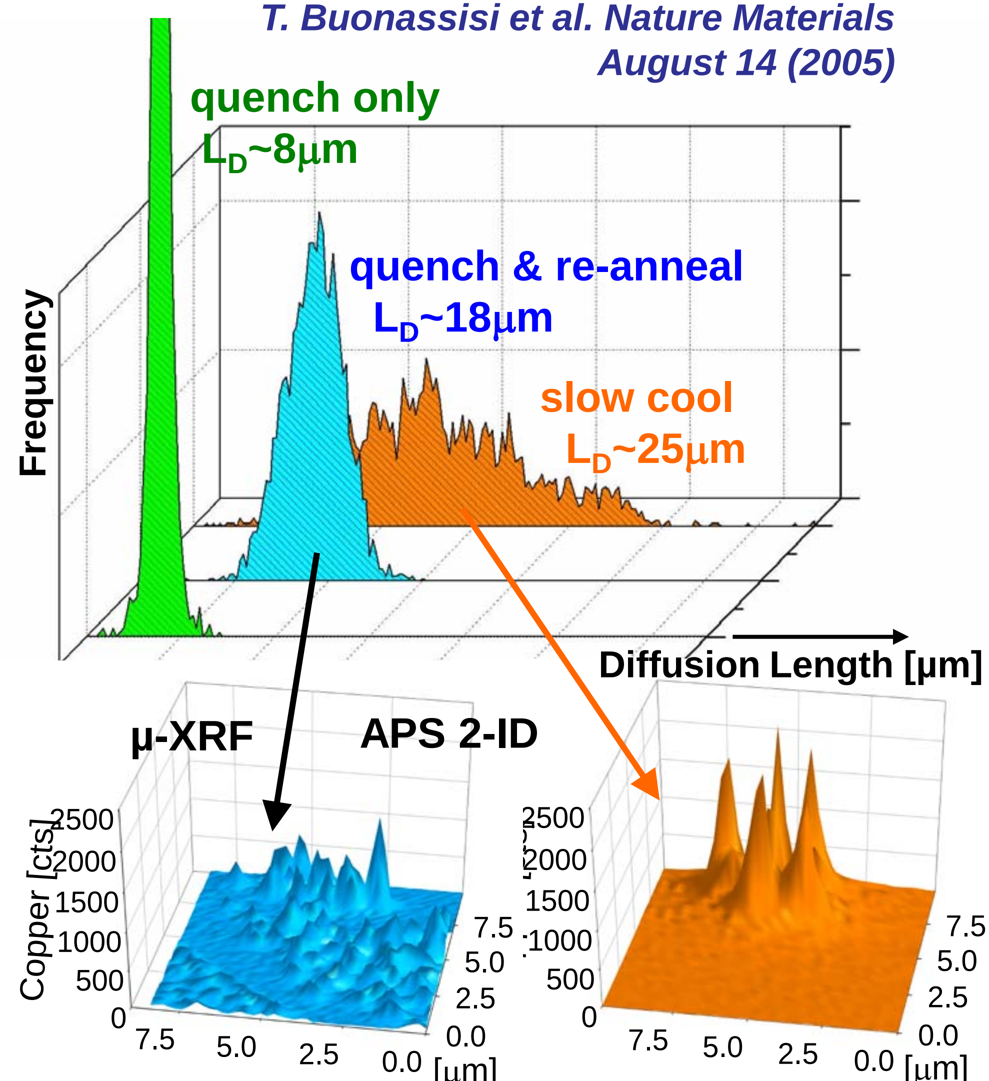




Defect Engineering Aided by μ-XRF Imaging & μ-spectroscopy

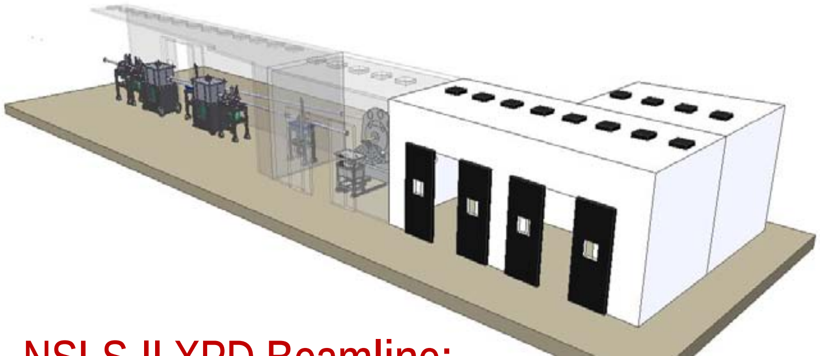
Multicrystalline (mc-Si)

T. Buonassisi et al. Nature Materials August 14 (2005)

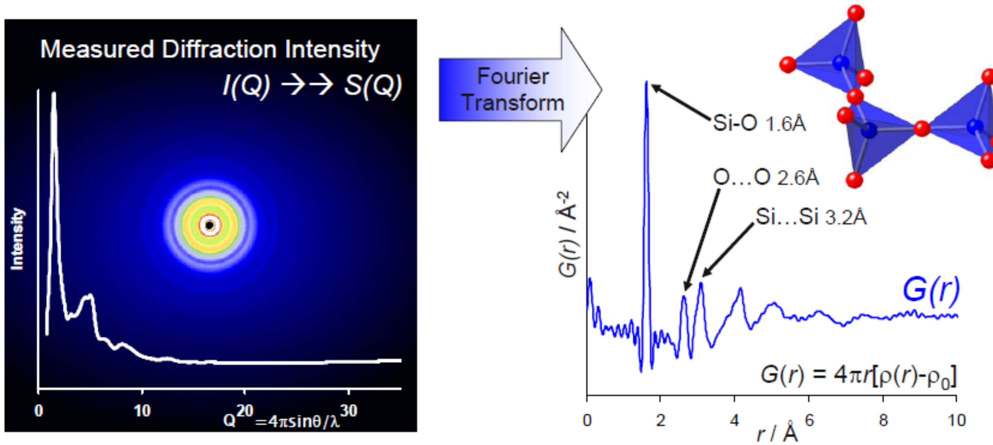


- Multicrystalline Si is viable alternative to monolithic Si for solar cells
- X-ray fluorescence microscopy is used to identify defect regions in mc-Si and to develop process to improve device performance
- NSLS-II x-ray nanoprobe will enable nm-scale defect engineering in wide range of materials including advanced glass materials (e.g. BMG)

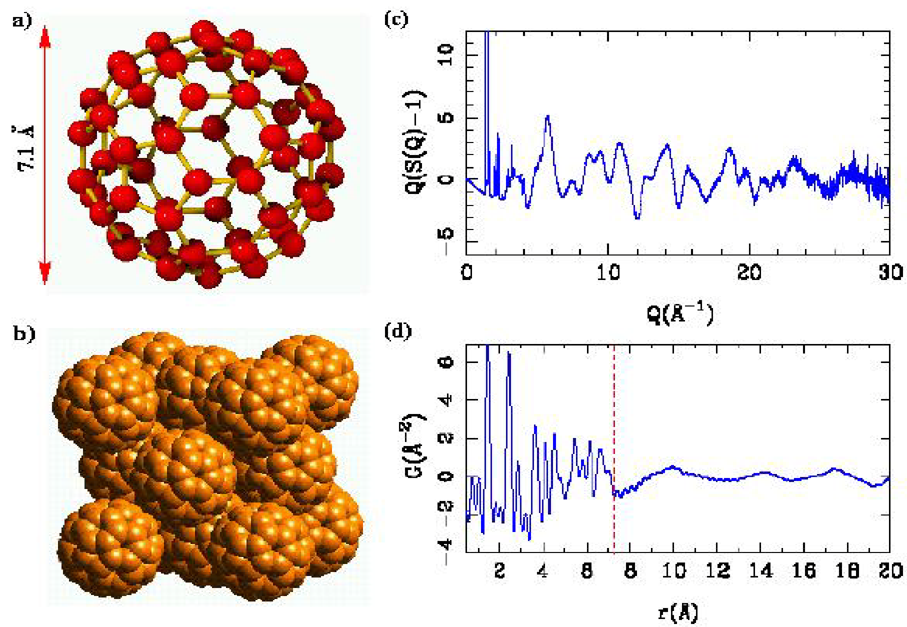
Pair Distribution Function Study of Disorder & Nanoparticles



<u>NSLS-II XPD Beamline</u>:
S. Billinge (Columbia), P. Chupas (ANL), J. Parise (SBU), L. Ehm (SBU/BNL); J. Hanson (Chemistry, BNL); J. Kaduk (INEOS Technologies); P. Stephens (SBU)

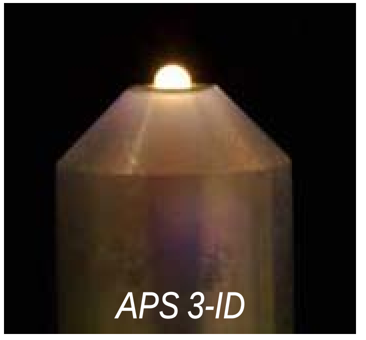


- Pair distribution function (PDF) is a powerful method to study short-range order or disorder, beyond powder diffraction for crystalline materials
- NSLS-II will offer dedicated PDF branch at the X-ray Powder Diffraction (XPD) beamline on high-flux wiggler ➔ emphasis on in-situ and extreme conditions

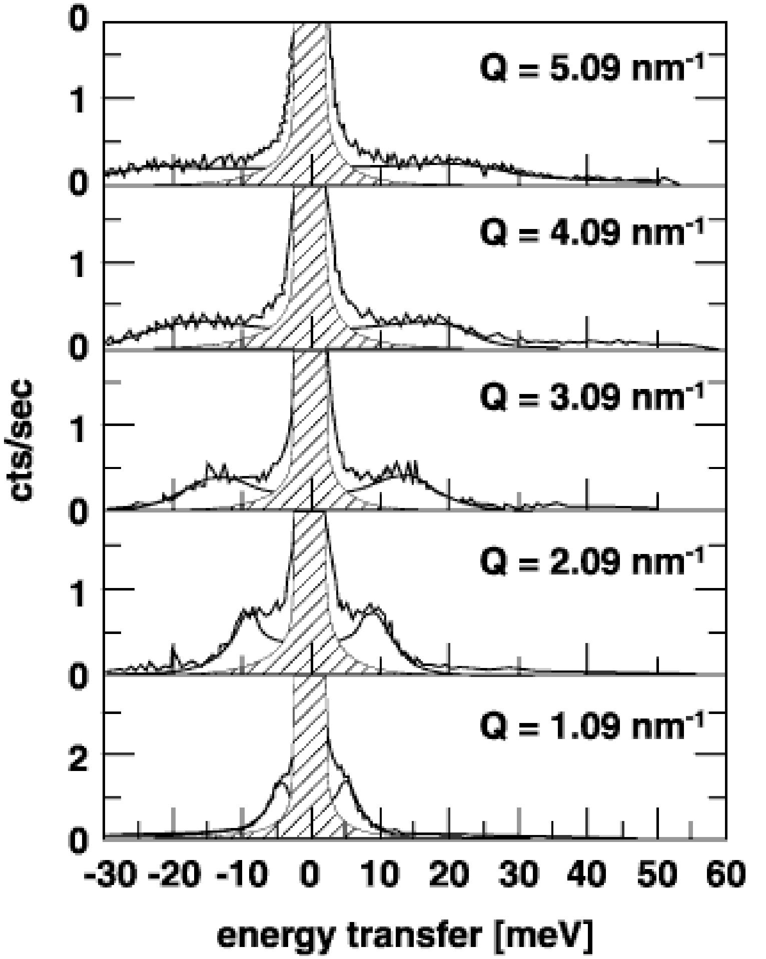


High-Resolution Inelastic X-ray Scattering (IXS)

Levitated liquid-aluminum-oxide sample in a super-cooled state at ~1800 C. The sample is levitated by an oxygen gas stream and heated by a 270W CO_2 laser



- IXS provides information on important transport properties such as speed of sound in disordered materials
- Similar to most x-ray experiments, IXS can be applied in extreme conditions such as high temperature and high pressure
- NSLS-II will offer ultra-high energy resolution of 0.1 meV in IXS experiments ➔ much enhanced capabilities for studying disordered, glassy materials



IXS spectra at 1.8 meV resolution (APS 3-ID) from liquid aluminum oxide at 2323K

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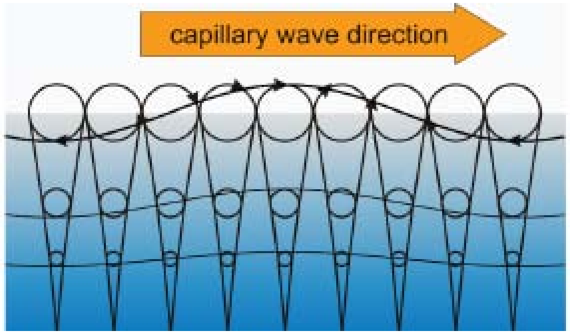
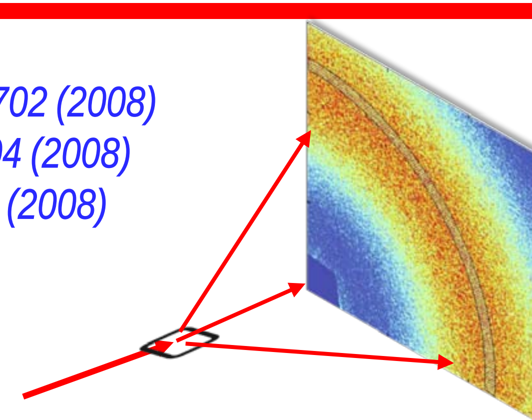
H. Sinn, et al, Science 299, 2047 (2003).

XPCS Study of Glass Transition Dynamics in Disordered Matter

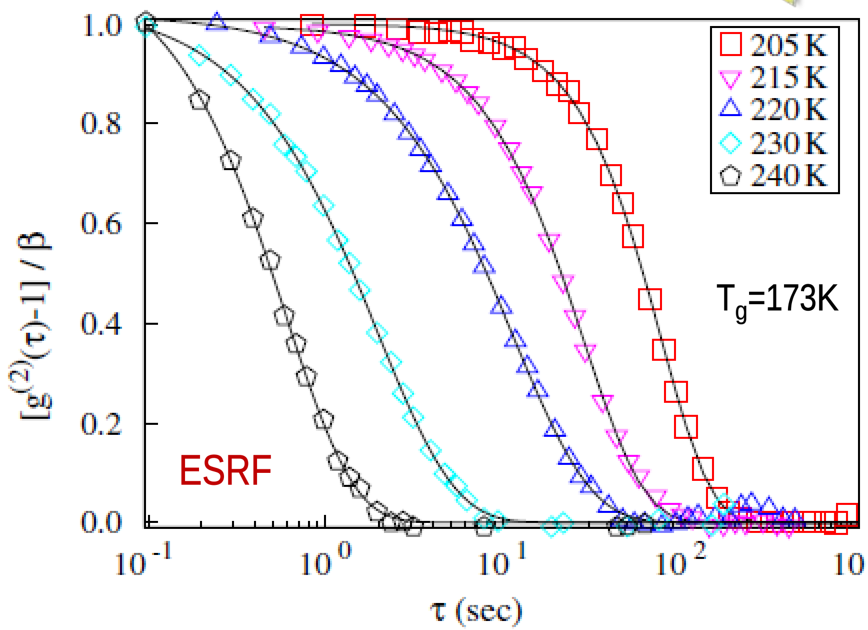


Caronna, et al., PRL 100, 055702 (2008)
Jiang, et al., PRL 101, 246104 (2008)
Lu, et al., PRL 100, 045701 (2008)

$$\mathrm{SNR} \propto B\, \tau^{1/2}\, S(q)$$

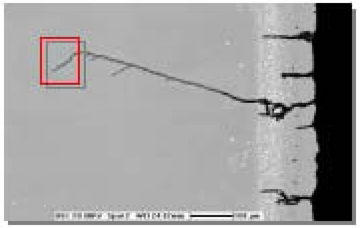


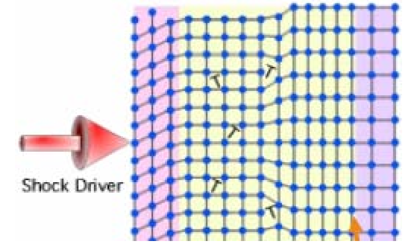
- X-ray photon correlation spectroscopy (XPCS) measures coherent scattering pattern and observes fluctuations in the scattering pattern
- XPCS study of suspended nanoparticles on a supercooled glass-forming liquid ➔ dynamics on how capillary waves slows down & freeze out near the glass transition
- At T >> T_g the particles undergo Brownian motion; measurements closer to glass transition (T ~ 1.2 T_g) indicate hyperdiffusive behavior
- Elastic behavior of supercooled liquids is poorly understood, and non-invasive experimental methods such as XPCS are essential in this field of study

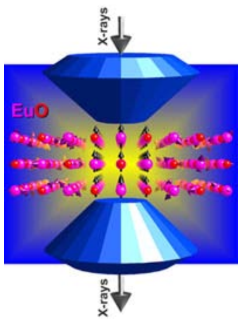


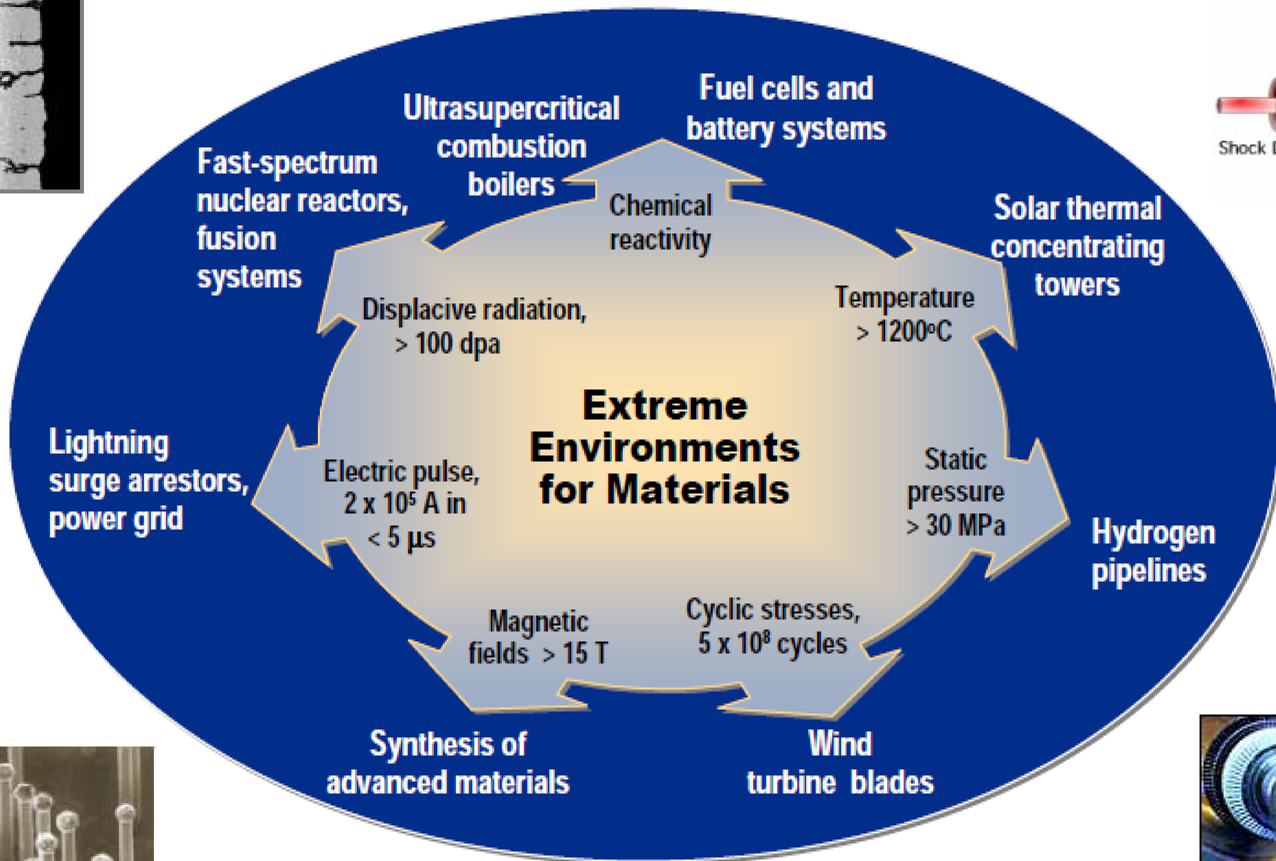
- High brightness at NSLS-II ➔ dynamics at much faster time scales (μsec)

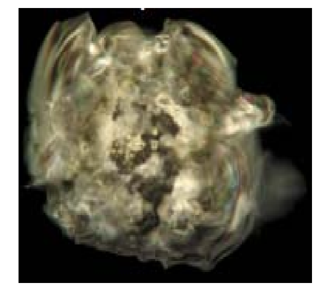
Bright X-ray Probes – Enable Amorphous Materials Studies in Extreme Environment

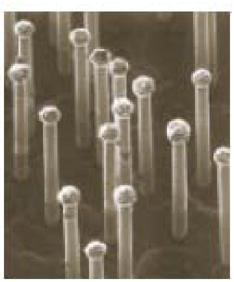


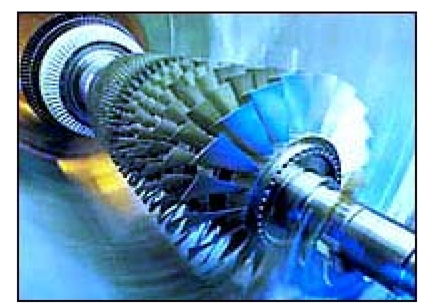












DOE/BES Basic Research Needs Workshop on Materials Under Extreme Environments

http://www.sc.doe.gov/bes/

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Pressure-Volume EOS of Amorphous Phase

PNAS 105, 13229 (2008)

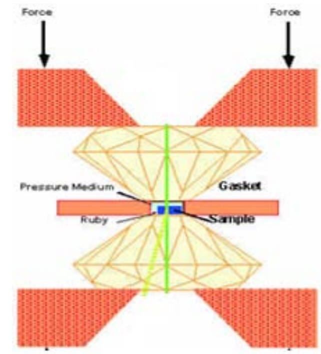
PNAS

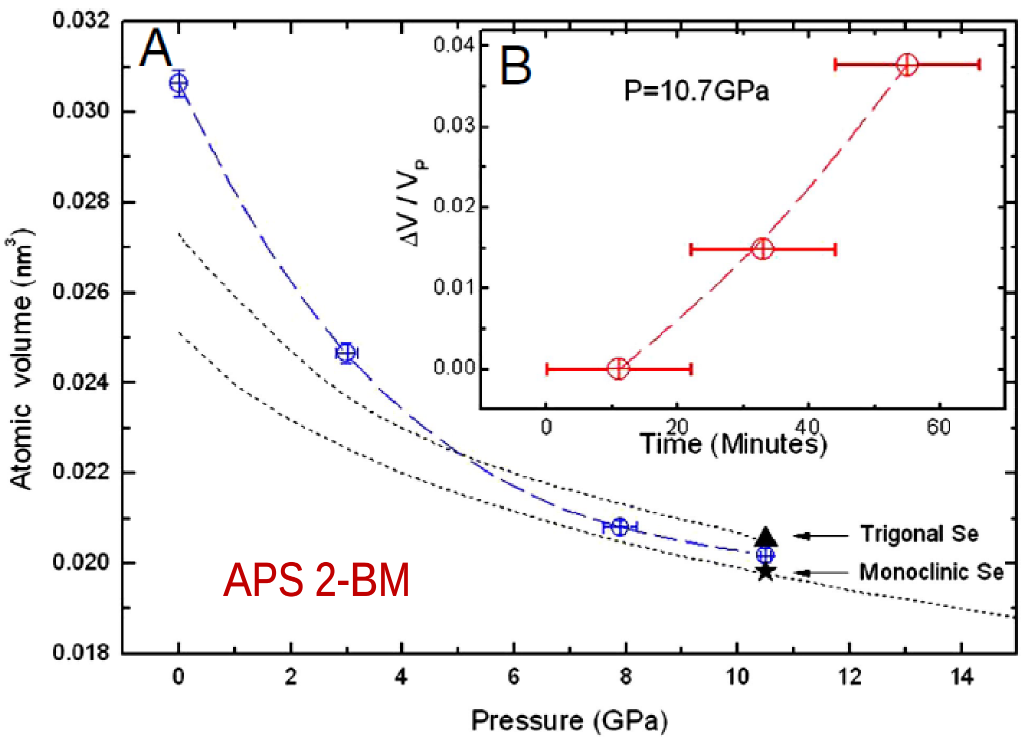
Anomalous high-pressure behavior of amorphous selenium from synchrotron x-ray diffraction and microtomography

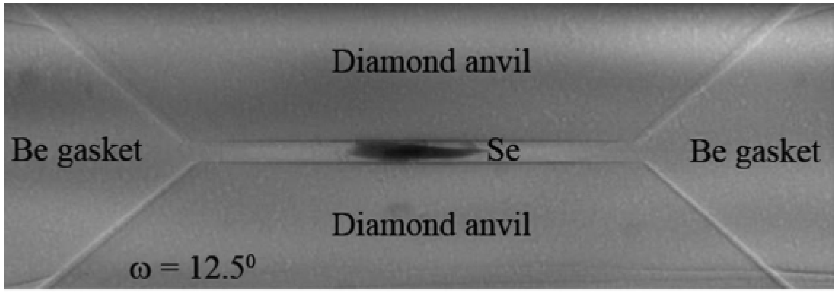
Haozhe Liu*[†], Luhong Wang*, Xianghui Xiao[‡], Francesco De Carlo[‡], Ji Feng[§], Ho-kwang Mao[¶], and Russell J. Hemley[‡¶]

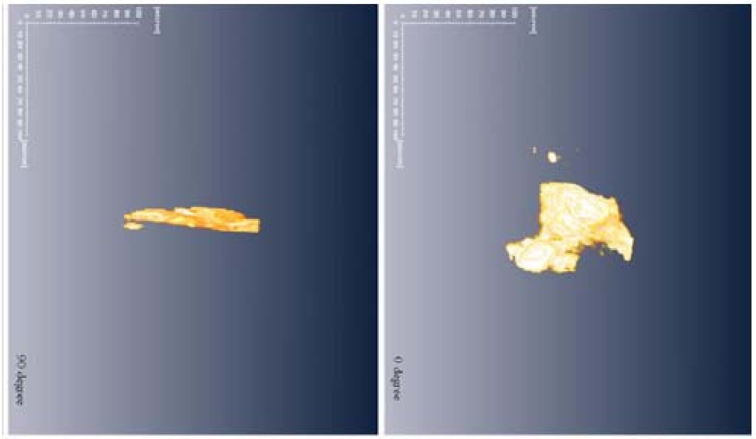
*Natural Science Research Center, Academy of Fundamental and Interdisciplinary Sciences, Harbin Institute of Technology, Harbin 150080, China; [‡]XOR, Advanced Photon Source, Argonne National Laboratory, Argonne, IL 60439; [§]Department of Chemistry and Chemical Biology, Harvard University, Cambridge, MA 02138; and [¶]Geophysical Laboratory, Carnegie Institution of Washington, Washington, DC 20015

Contributed by Russell J. Hemley, July 16, 2008 (sent for review June 2, 2008)





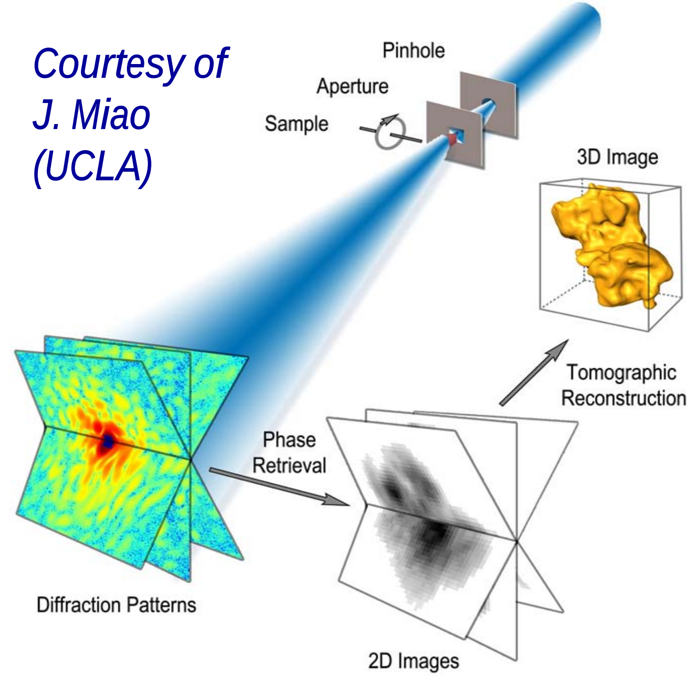




Coherent X-ray Diffraction Imaging (CDI)

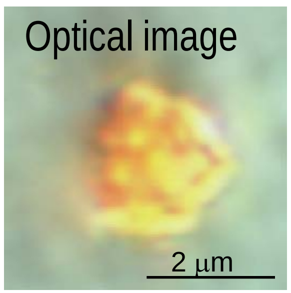
- Coherent diffraction microscopy is much like crystallography but applied to noncrystalline materials
- Requires a highly coherent x-ray beam (available at NSLS-II) and iterative phase retrieval

Courtesy of J. Miao (UCLA)

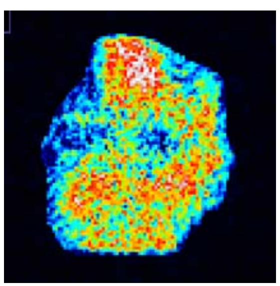


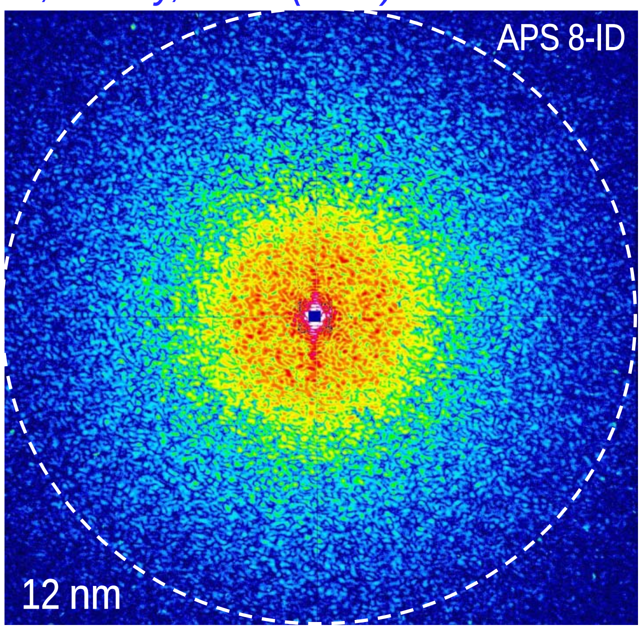
Example: structure of nanoporous gold

Xiao, Shen, Sandy, et al. (APS)

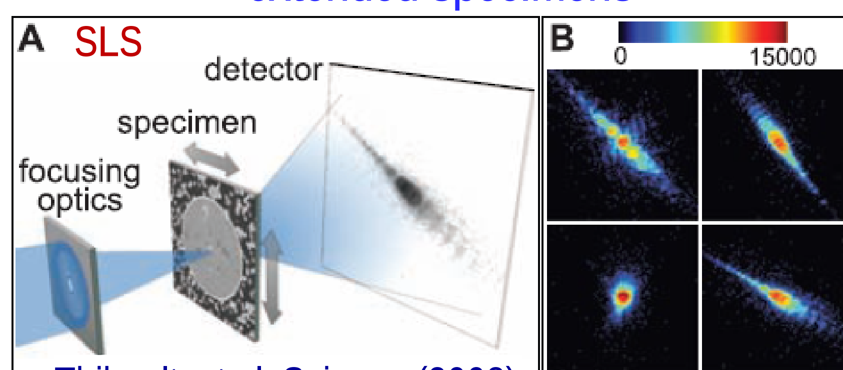


Reconstructed image





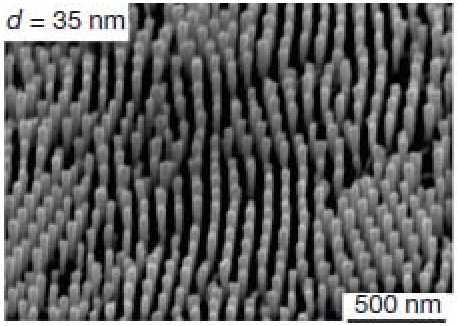
CDI combined with STXM: allows study of extended specimens

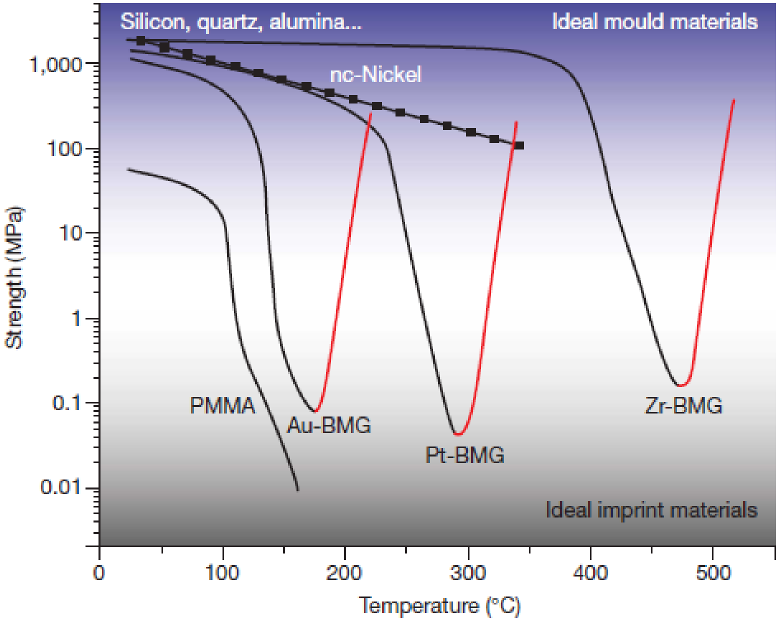


Thibault, et al, Science (2008)

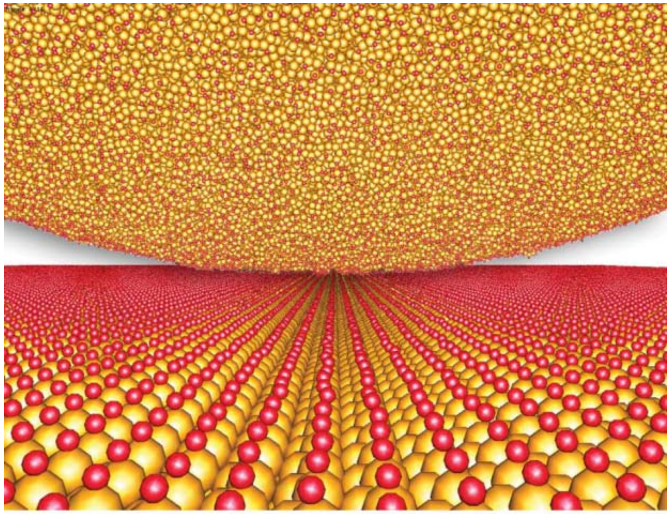
Engineering Applications of Amorphous Materials

"Nanomoulding with amorphous metals"
G. Kumar *et al, Nature 457, 868 (2009).*





- Amorphous materials can provide unique properties that are not fundamentally limited by grain sizes and molecular dimensions
- They offer unique opportunities to (a) study fundamental engineering physics such as friction at nano-scales, and (b) applications in nanofabrication / nano-imprinting
- SR such as NSLS-II may be useful in in-situ observations of these advanced studies and engineering processes.



"Friction law at nanoscale"
Y. Mo *et al, Nature 457, 1116 (2009).*

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Summary

- NSLS-II will be a high-brightness synchrotron facility for a broad range of photon energies
- It will offer much enhanced capabilities in nanodiffraction, scanning x-ray microscopy, coherent imaging, and time-resolved in-situ studies of material structure and function
- It will enable new, exciting research opportunities in amorphous materials because of the much enhanced capabilities
- We look forward to working with scientific community to build up strong scientific programs and advanced synchrotron capabilities at NSLS-II