Neutron X-ray Summer School, July 18, 2022

Synchrotron Radiation User Facilities

Jonathan Lang
Director X-ray Science Division
Advanced Photon Source
Argonne National Laboratory

UChicago Argonne, LLC

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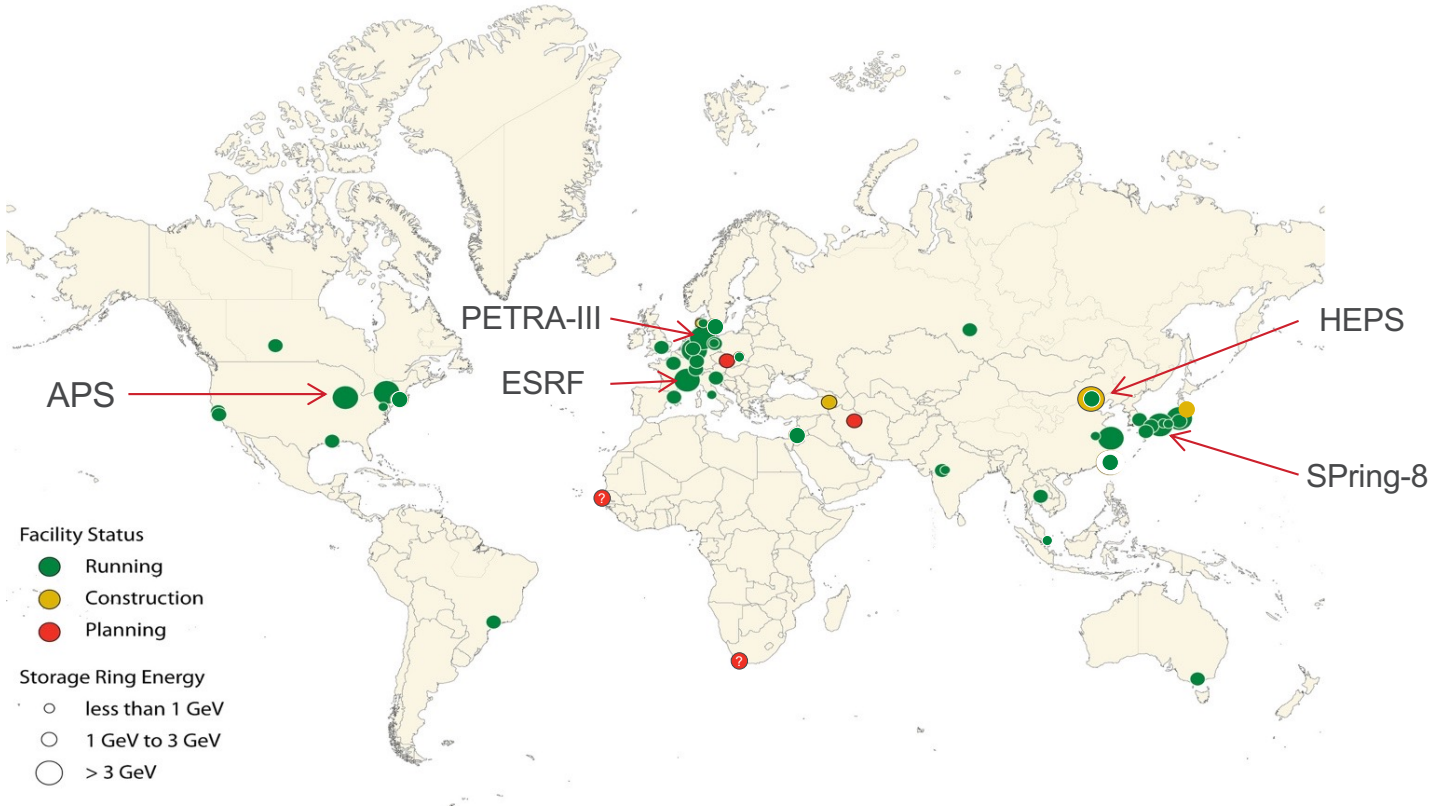
SYNCHROTRON FACILITIES AROUND THE WORLD

Over 35 major synchrotron facilities world-wide



Over 40,000 scientists use these facilities each year.

Five are large-circumference high-energy (>5 GeV) high-brilliance (<3nm-rad) storage rings

SYNCHROTRON LIGHT SOURCES IN NORTH AMERICA

8 light sources; 5 DOE US; 1 NSF US; 1 State US; 1 Canadian

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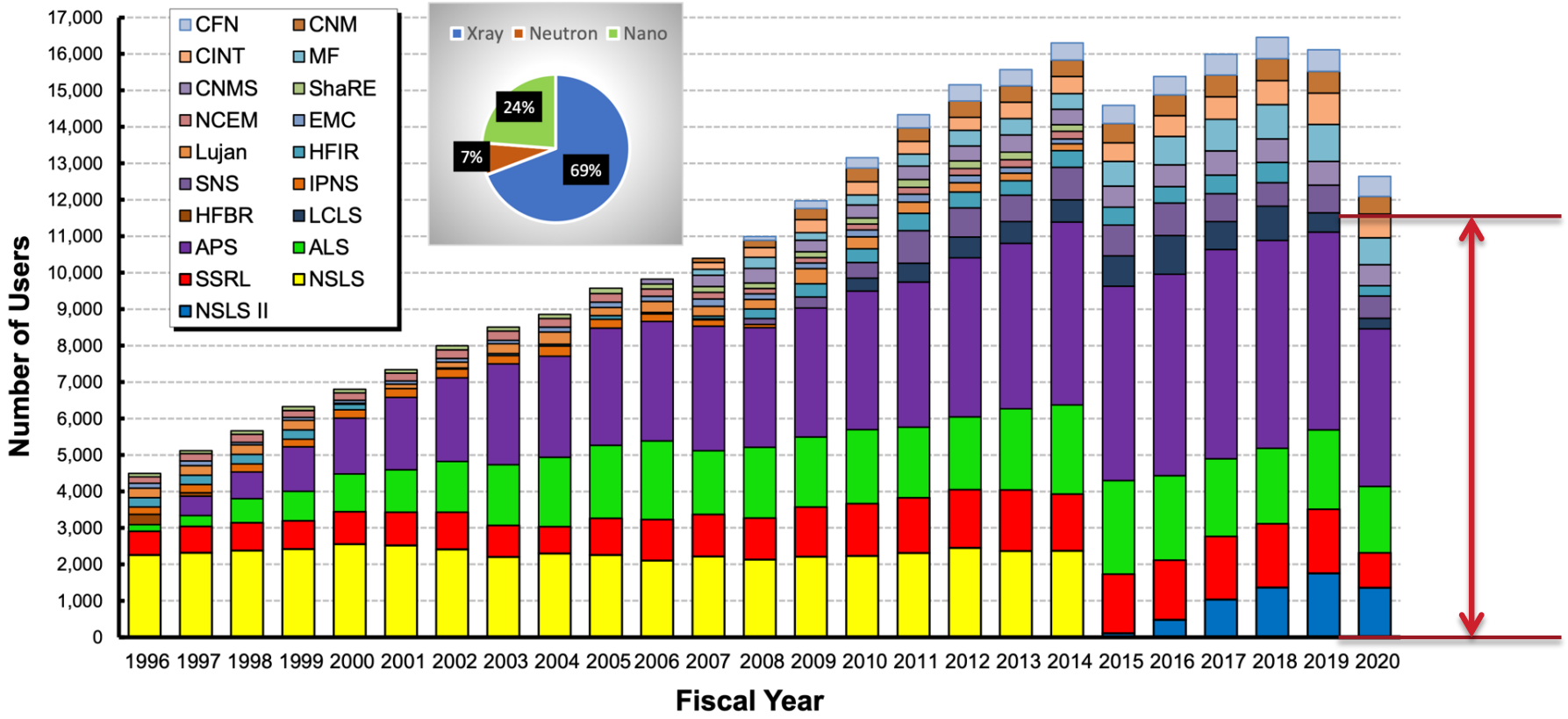
LIGHT SOURCE PARAMETERS

Source	Energy	Current	Circum.	Emittance	# Beamlines
APS	7.0 GeV	100 mA	1104m	3.0 nm-rad	67 (41 ID)
APS-U	6.0 GeV	200 mA	1104m-δ	0.042 nm-rad	~same
NSLS-II	3.0 GeV	400 mA	792m	0.75 nm-rad	28 (22 ID)
SSRL	3.0 GeV	500 mA	234m	10 nm-rad	27 (18 ID)
ALS	1.9 GeV	500 mA	199m	2.0 nm-rad	46 (17 ID)
CHESS	6.0 GeV	200 mA	768m	27 nm-rad	7
CLS	2.9 GeV	250 mA	170m	18.1 nm-rad	20 (13 ID)
CAMD	1.3 GeV	200 mA	55m	200 nm-rad	15 (3 ID)

LCLS – X-ray free electron laser accelerator, so parameter don't easily correlate

DOE SCIENTIFIC USER FACILITIES

More than 11,000 unique users use one of the DOE light sources each year; Canadian Light Source ~1000; CHESS ~1000



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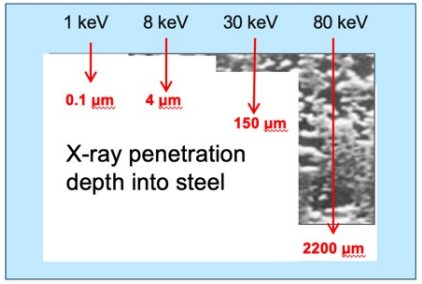
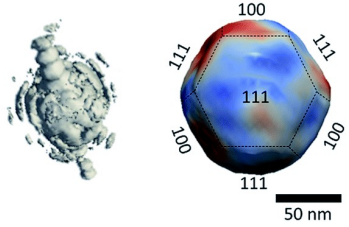
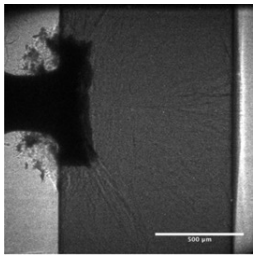
WHY CHOOSE PARTICULAR FACILITY?

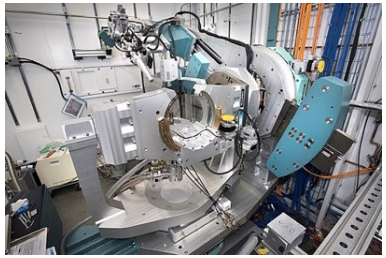
Considerations for your experiment

- Energy range for x-rays
  - Higher energy storage rings generate ”harder” x-rays
    - Penetration, complex environments, in-situ/operando, …
  - Lower energy rings – light elements, electronic and magnetic sensitivity, ..
- Brightness
  - Enables smaller focal spots & coherence measurements
- Timing structure
  - Pulse structure suitable if doing ultra-fast experiments
    - Pump-probe; high-speed imaging
- Specialized capabilities
  - Unique measurements (i.e. beam polarization, magnetic field, stress/strain equipment, furnaces, laser heating, gas handling, …
  - Ancillary labs capabilities (i.e. electrochemistry, high pressure, …)
- Location
  - Similar capabilities for some techniques (i.e. XAS, SAXS, …)
  - Easier to transport your own equipment.





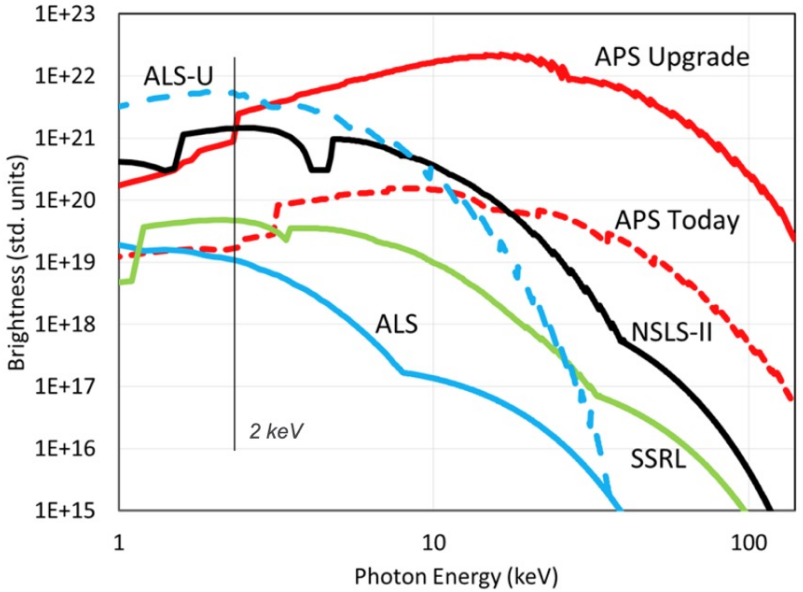


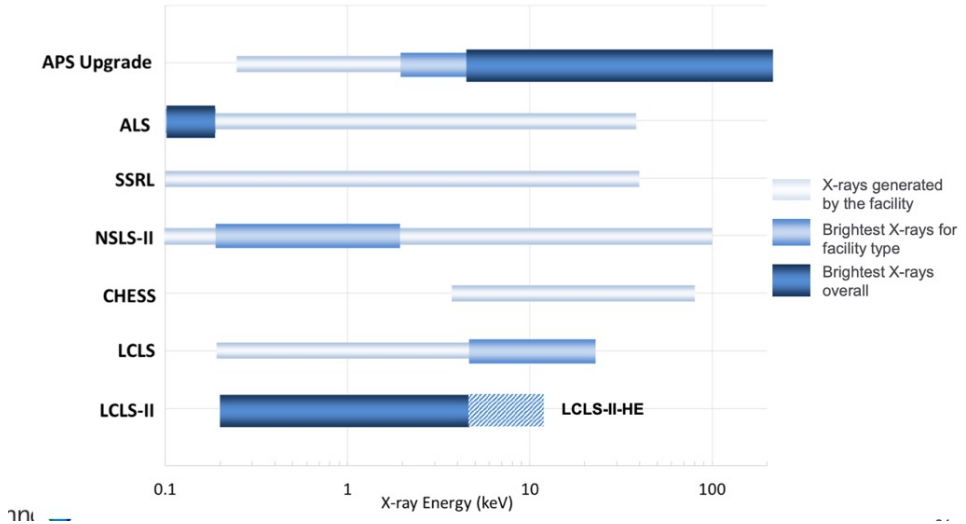


Remote Access

DOE LIGHT SOURCE FACILITIES

Light sources optimized* for particular energy ranges



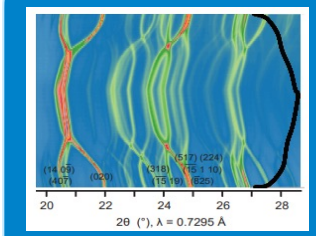


- Harder x-rays contain significant power in the x-ray beam
- Lower energy ring can go to higher current without heat load mitigation

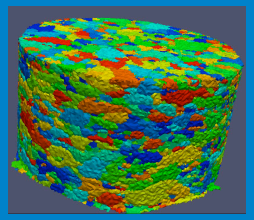
LIGHT SOURCE FACILITIES

Spectral range

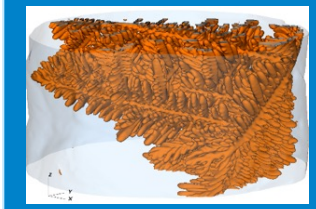
Hard X-ray (>20 keV)



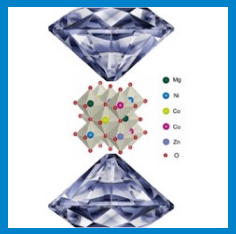
In-operando XRD



HighE Diff. Micro.



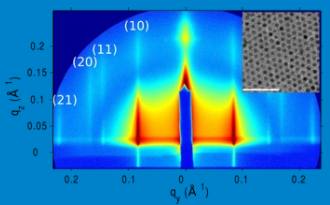
Dynamic Tomography



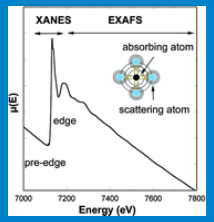
High-Press. XRD

PDF, HEDM, XRD, High Press., Tomography, ….

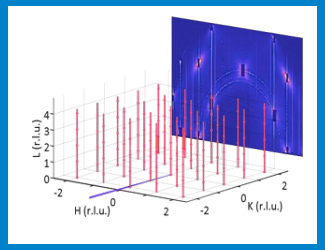
X-rays (5-20 keV)



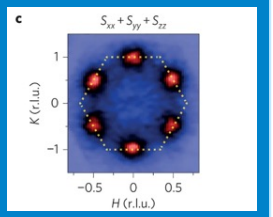
GI-SAXS



XAS



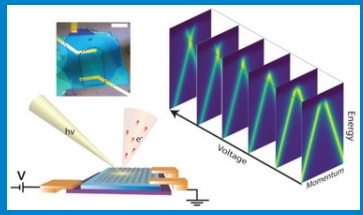
Surface Diffraction



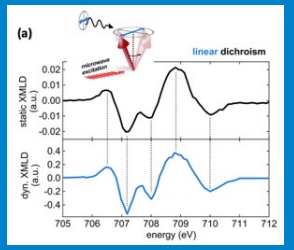
RIXS (3d K, 5d L)

SAXS, XAS, Diffraction, XRF, Spectro-microscopy, ….

Soft X-ray (<3 keV)



Angle Resolved Photoemission

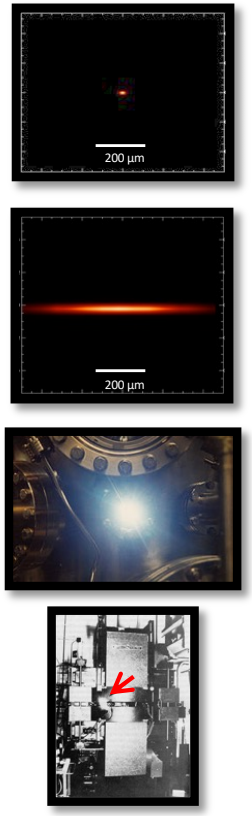


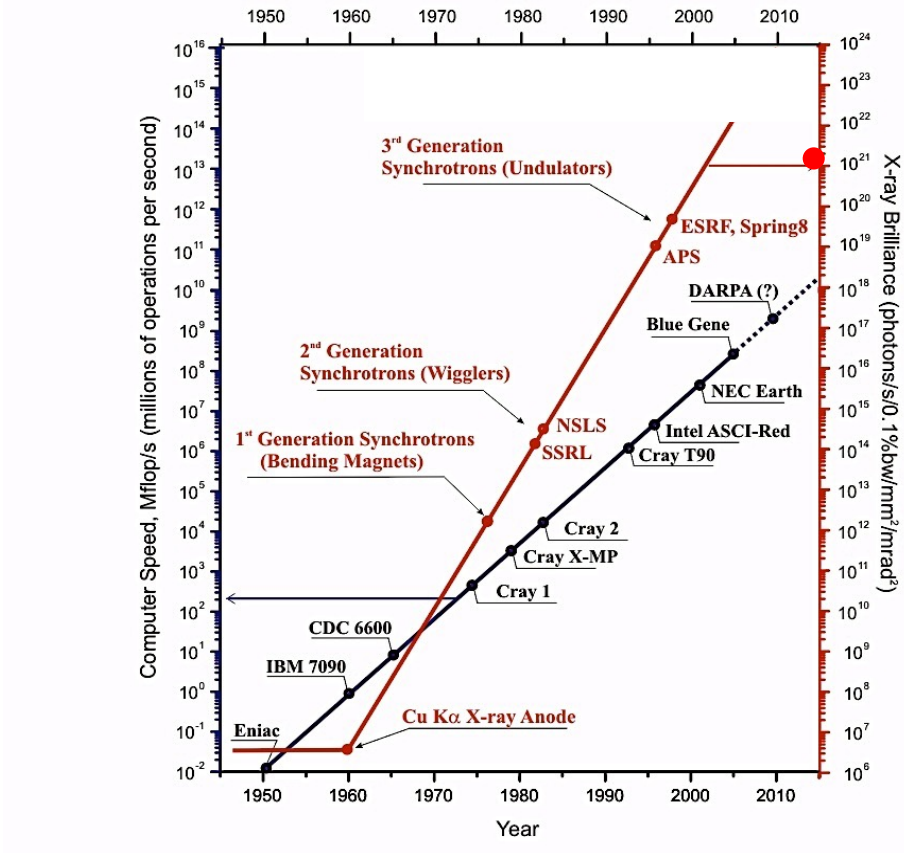
X-ray magnetic dichroism

ARPES, XMCD, Imaging, Light elements, …

Facilities will offer range of capabilities even outside their “sweet” spot.

EVOLUTION OF SYNCHROTRON BRIGHTNESS



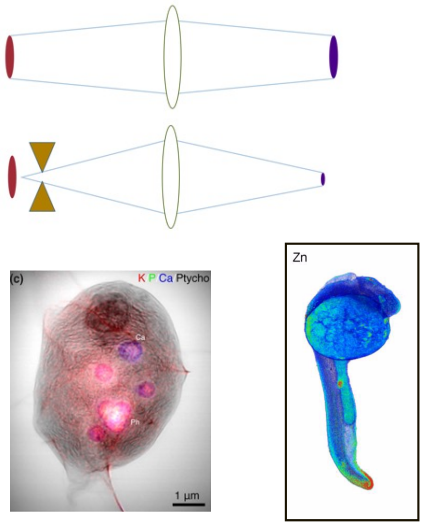


≥ 2 orders of magnitude increase in brightness between generations

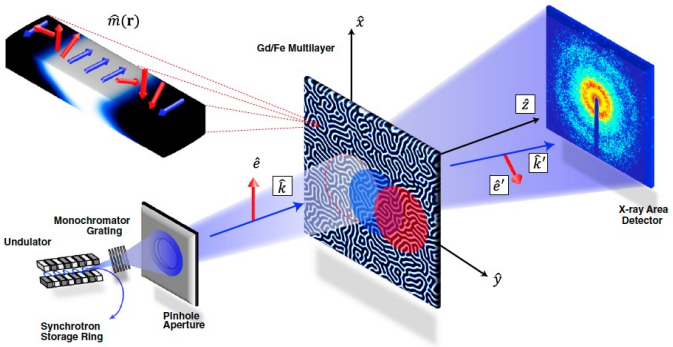
DOE SCIENTIFIC USER FACILITIES

Brightness & Beam Coherence

Focusing of x-ray beam

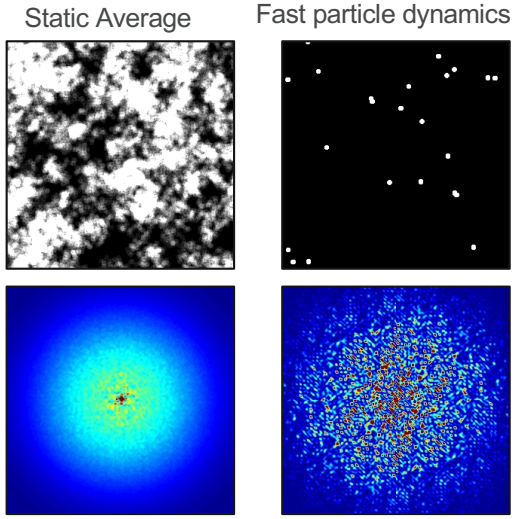


Forward Scatting Ptychography



A. Tripathi *et al., PNAS* **108**, 13393 (2011)

X-ray Photon Correlation Spectroscopy



Simulation courtesy of Z. Jiang (APS)

Brightness enables focusing of all x-rays into nanometer scale focal spots

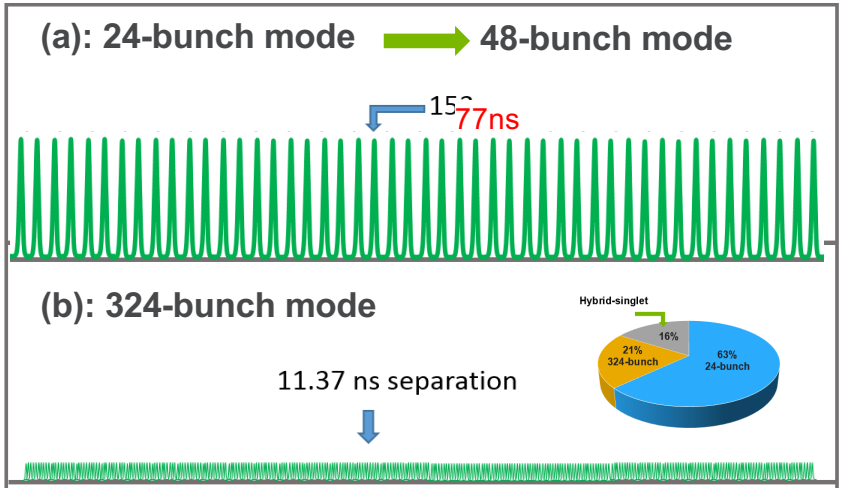
Enables lensless imaging & studies of dynamics using correlation methods

See talks by Chris Jacobsen, Ross Harder tomorrow & Larry Lurio on Wednesday

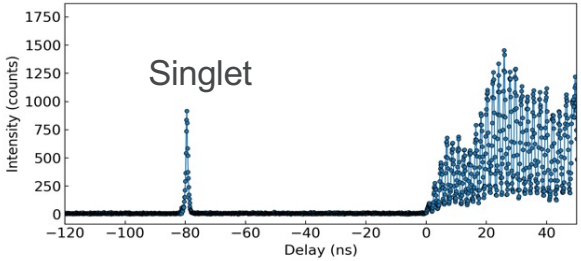
LIGHT SOURCE FACILITIES

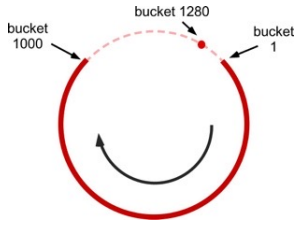
Timing modes

APS operates majority of the time (~80%) in a fill pattern that enables pump-probe (and other) timing studies



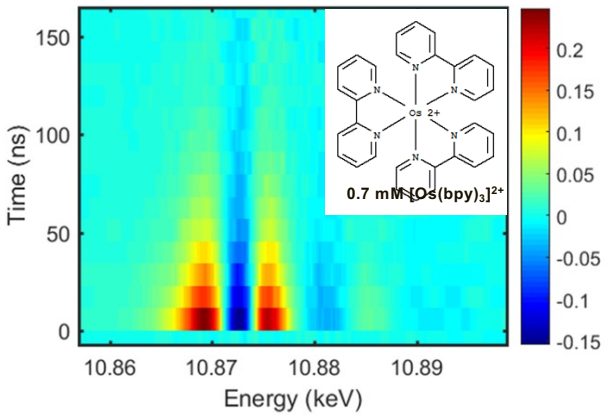
NSLS-II 1320 Buckets; 1056 filled; *2 ns separation*





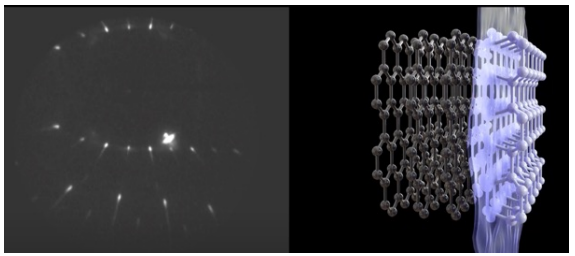
Time-Resolved X-ray Absorption

Os L_{III} edge difference XAS



E. Kinigstein *et al., Rev. Sci. Instrum.* **92**, 085109 (2021)

Single pulse x-ray diffraction @ APS 35-ID



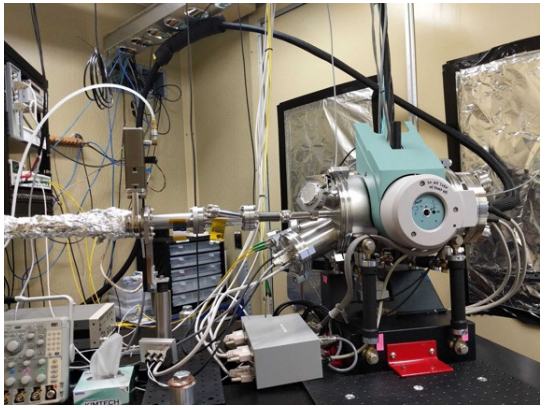
See talks by Linda Young, & Paul Fouss on Wednesday

LIGHT SOURCE FACILITIES

Beamline capabilities

Nanoprobe @ APS

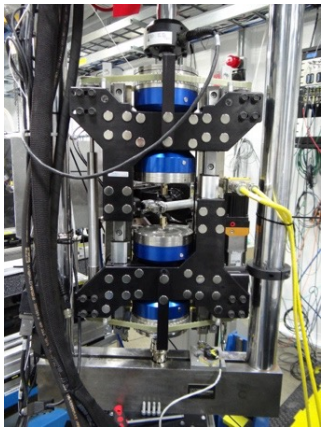
Soft X-ray RIXS @ NSLS-II



COSMIC imaging @ ALS

MEC instrument @ LCLS

AMPIX electrochemical cells @ APS



RAMS instrument @ APS

- Ancillary capabilities at each beamline typically given on web pages

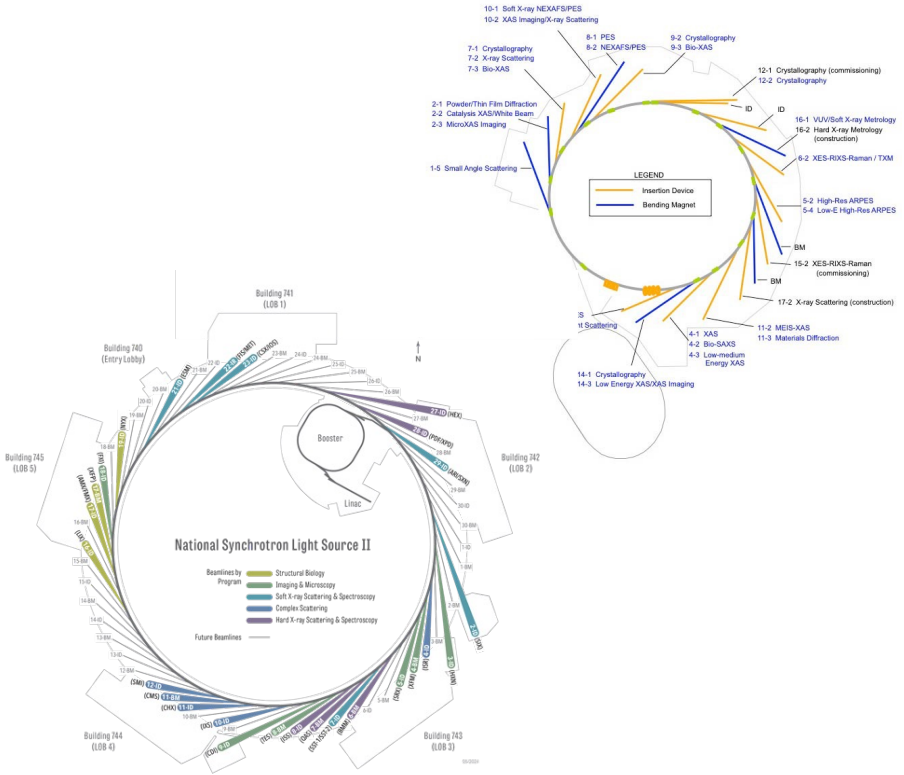
LIGHT SOURCE FACILITIES

Beamline capabilities information

Beamlines Directory

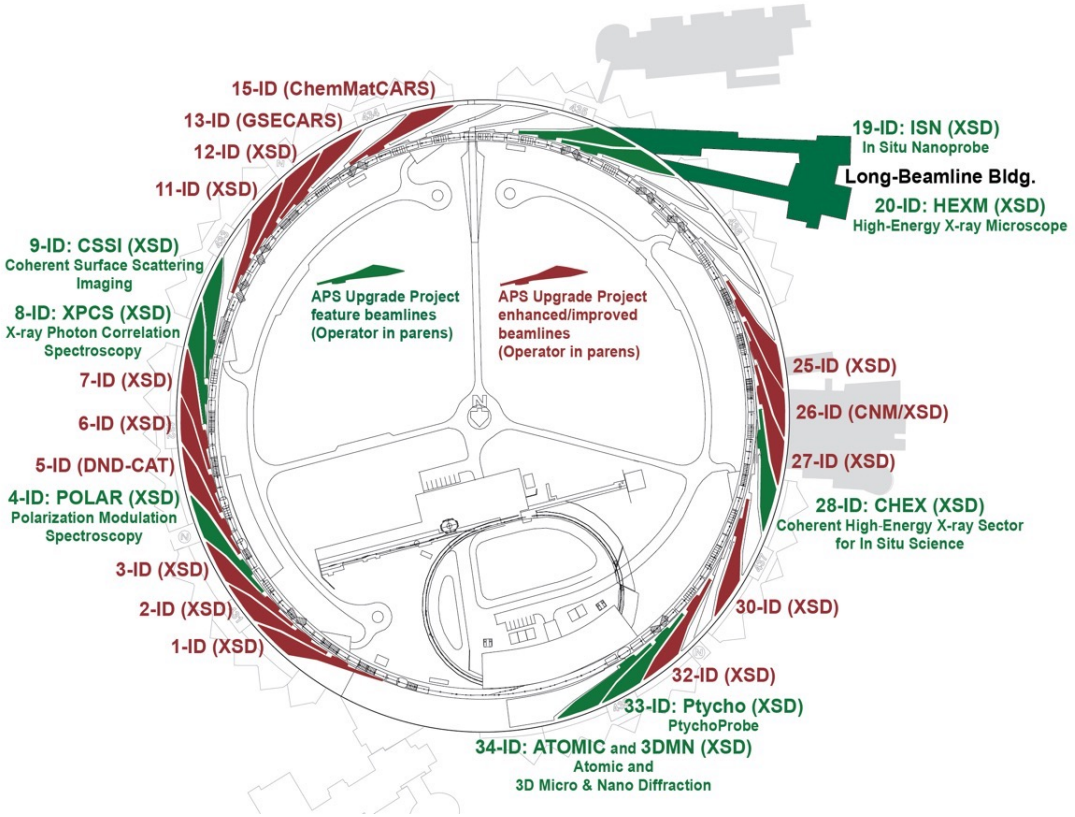
Information on APS Operations and General User Programs During the COVID Pandemic. To determine what access modes are available to general users at this time, check the operational status of the APS - Read More

Beamline	Disciplines	Techniques	Energy Range	Access	Operator	Status
1-BM-B,C	• Materials Science • Physics	• Optics testing • Detector testing • Topography • White Laue Single Crystal Diffraction	• 6-30 keV • 50-120 keV	• On-site	XSD	
1-ID-B,C,E	• Materials Science • Physics • Chemistry • Life Sciences	• High-energy x-ray diffraction • Tomography • Small-angle x-ray scattering • Fluorescence spectroscopy • Pair distribution function • Phase contrast imaging	• 41-136 keV • 45-116 keV	• On-site	XSD	
2-BM-A,B	• Physics • Life Sciences • GeoScience • Materials Science	• Tomography • Phase contrast imaging	• 10-170 keV • 11-35 keV	• On-site	XSD	
2-ID-D	• Life Sciences • Materials Science • Environmental Science	• Microfluorescence • Micro x-ray absorption fine structure • Nano-imaging • Ptychography	• 5-30 keV	• On-site • Remote • Mail-in • Beamline Staff	XSD	
2-ID-E	• Life Sciences	• Microfluorescence	• 5-20 keV	• On-site	XSD	



- Types of measurements supported at beamlines typically given on web pages
- Contact local beamlines staff with questions

APS UPGRADE PROJECT



- $815M upgrade; Reuses ~$1.5B in infrastructure
- Split ~½ accelerator & ~½ beamlines

- New storage ring, **42 pm** emittance @ 6 GeV, 200 mA
- New and updated insertion devices, including Superconducting Unds.
- Combined result in brightness increases of up to 500x
- 9 new feature beamlines + Long Beamline Building
- 15 enhanced and improved beamlines
- Exploit high performance computing, AI/ML

44 Petaflops

On-line Fall 21'

~2 Exaflop (2000 Petaflops)

Coming Fall 22'

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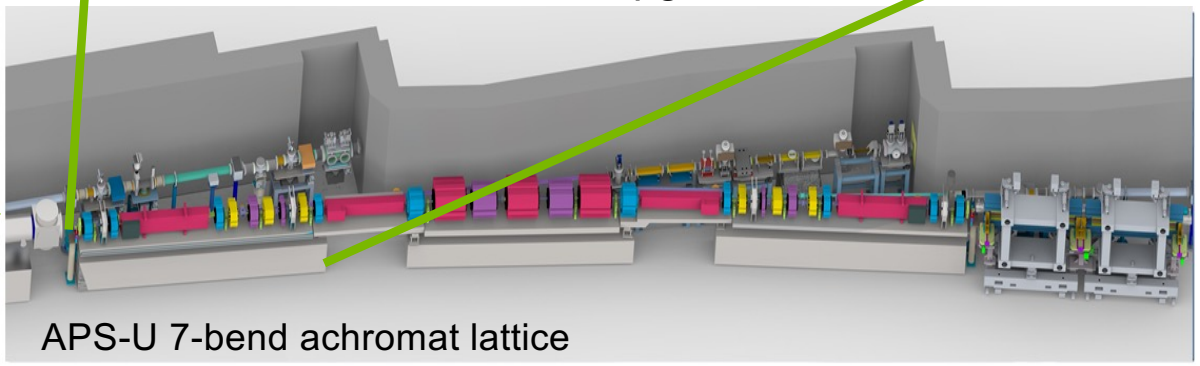
APS-U – HIGH BRIGHTNESS STORAGE RING LATTICE

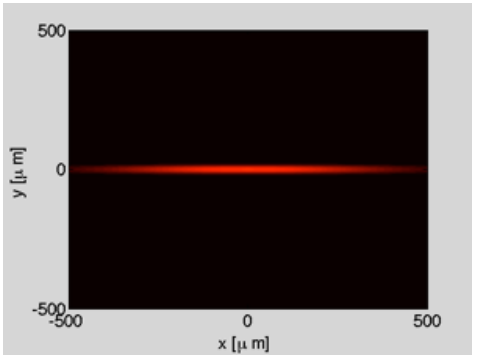
APS Upgrade



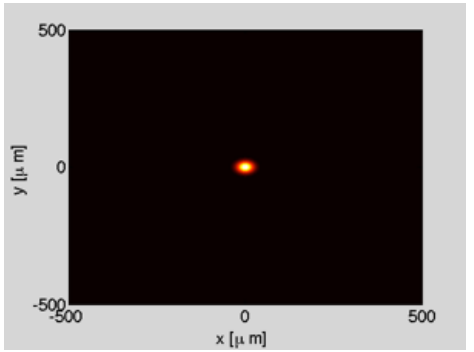
APS-U 7-bend achromat lattice

~ 70x reduction in horizontal emittance

APS Today



ε_o = 3100 pm



ε_o = 42 pm

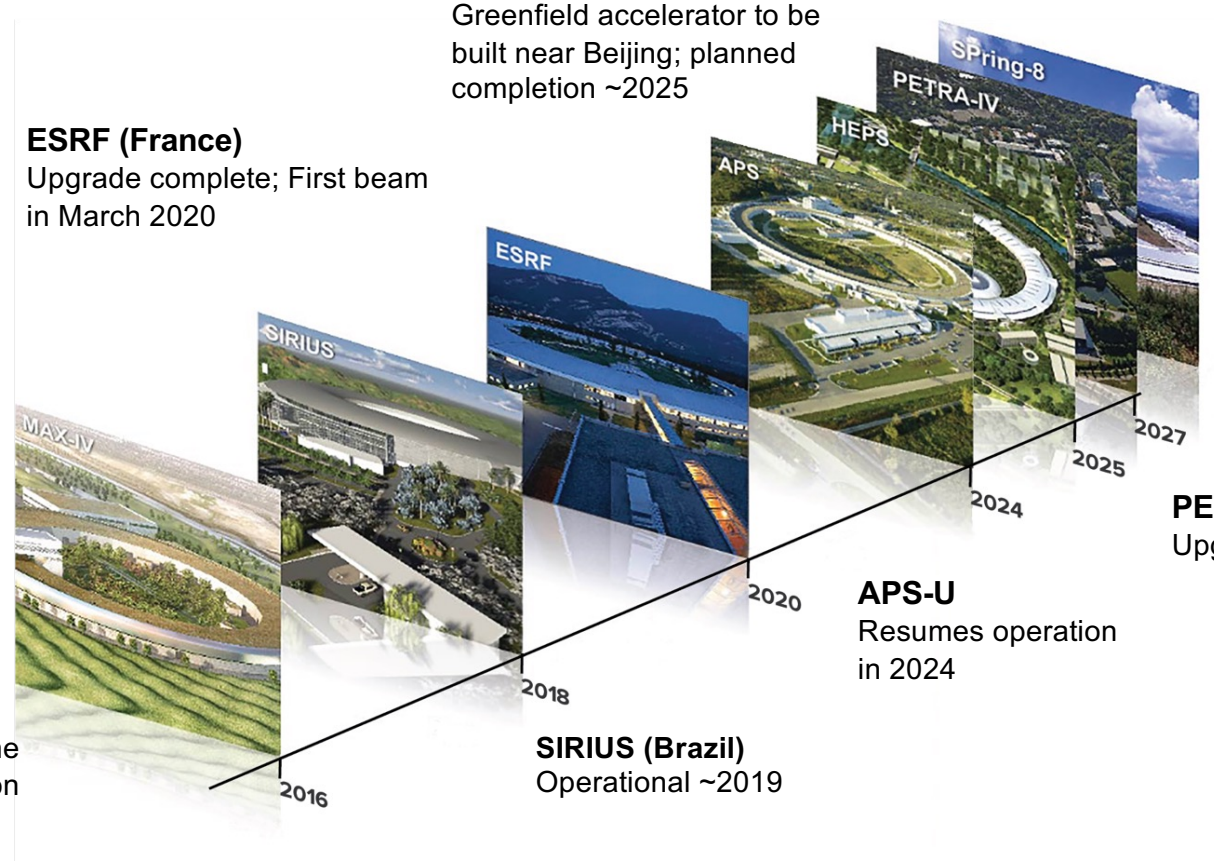
Completely replace the storage ring to dramatically decrease electron source size

World-Wide Light Source Upgrades

HEPS (China)
Greenfield accelerator to be built near Beijing; planned completion ~2025

ESRF (France)
Upgrade complete; First beam in March 2020

SPring-8 (Japan)
Upgrading >2027



PETRA-IV (Germany)
Upgrading 2027

APS-U
Resumes operation in 2024

MAX-IV (Sweden)
Inauguration June 2016; in operation

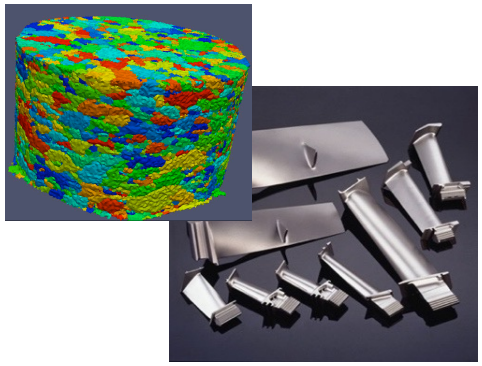
SIRIUS (Brazil)
Operational ~2019

HEXM: High Energy X-ray Microscopy (20-ID)

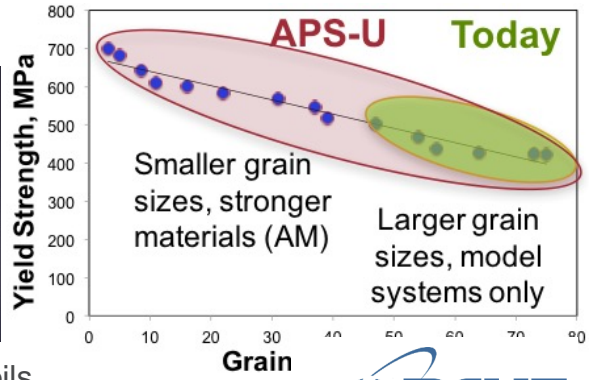
Long beamline for 3D materials characterization of engineering materials

HEXM will give new information:

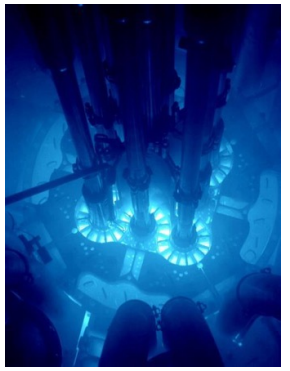
- Intra-granular structure (eg, ‘see’ crack initiation)
- Smaller grained materials (eg, energy storage, additive manufacturing)
- Dynamic processes (eg, fatigue)



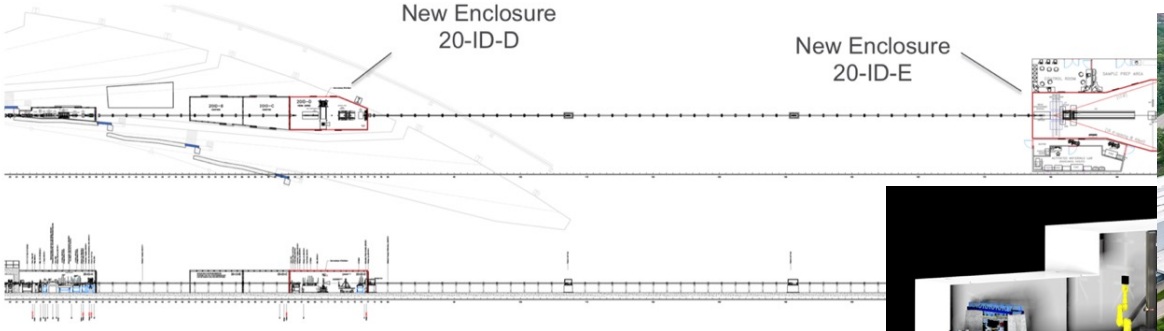
Process-enhanced properties for airfoils



Advanced Test Reactor



NSUF Nuclear Science User Facilities



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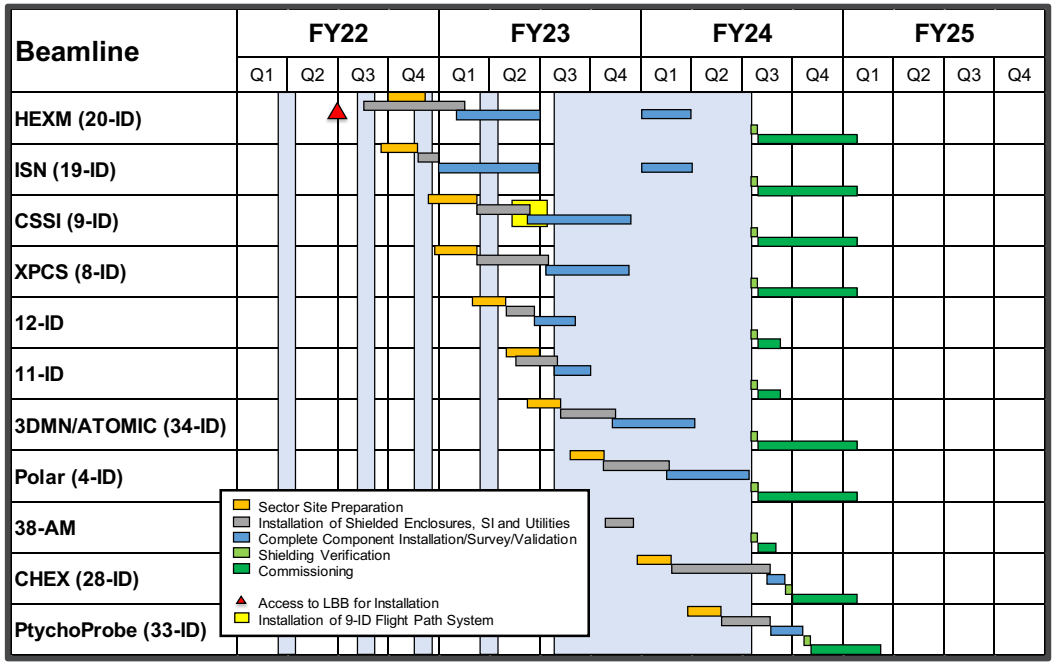
APSU BEAMLINE CONSTRUCTION SCHEDULE

Schedule driven by experimental enclosure delivery

- Downtime starts April 17, 2023
  - 273 days left
- Downtime duration 1 year
  - 1 month to remove current ring
  - 8 months to install new ring
  - 3 months to “commission” new ring
- Resume operations in ~May 2024
  - First ~month, each beamline needs to be re-enabled (shielding checked, etc.).
  - Start operations at 25-50 mA & ramp up to 200 mA within a year.

Schedule for major beamline work.

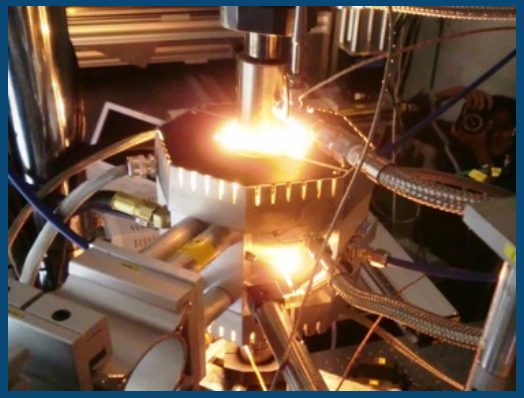


APS-U: THE ULTIMATE 3D MICROSCOPE

High Energy

Penetrating bulk materials and operating systems

- World's brightest source of hard x-rays
- 3D mapping deep inside samples
- X-ray cinematography in previously inaccessible regimes



Brightness

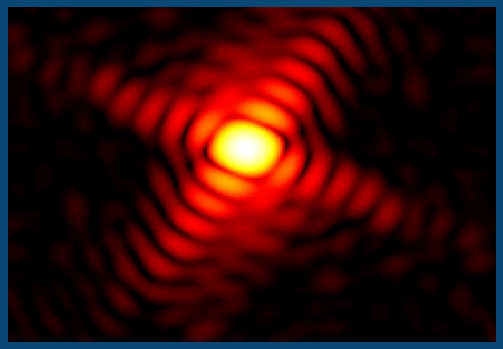
Providing macroscopic fields of view with nm-scale resolution

- Multi-scale imaging connecting nanometer features across macroscopic dimensions
- Fast sampling with chemical, magnetic, electronic sensitivity

Coherence

Enabling highest spatial resolution even in non-periodic materials

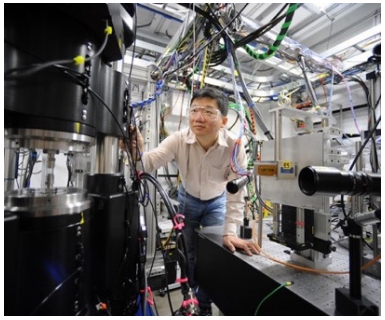
- Extends lens-less imaging to hard x-ray domain, with resolution down to <1 nm, localizing atoms
- Increases phase contrast for fast full-field imaging
- Correlation methods improve by 10,000x-1,000,000x

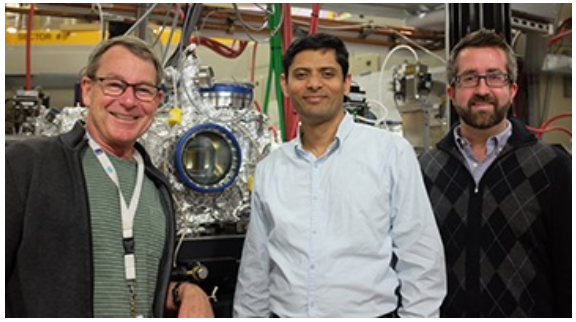


SUMMARY

Lots of considerations when choosing a beamline/facility
Can be daunting task.

- Energy range for measurement?
- Brightness needs?
- Timing structure important?
- Specialized sample/measurement capabilities needed?
- Location
  - Remote or Mail-in capabilities offered?





Staff at the facilities there to help you make the most effective use of your time. Talk to them, they can help guide you towards the best choice beamlines

QUESTIONS

Argonne NATIONAL LABORATORY