Overview of the ALS Upgrade

David Robin
Project Director, Advanced Light Source Upgrade
on behalf of the ALS-U team

October 26, 2016

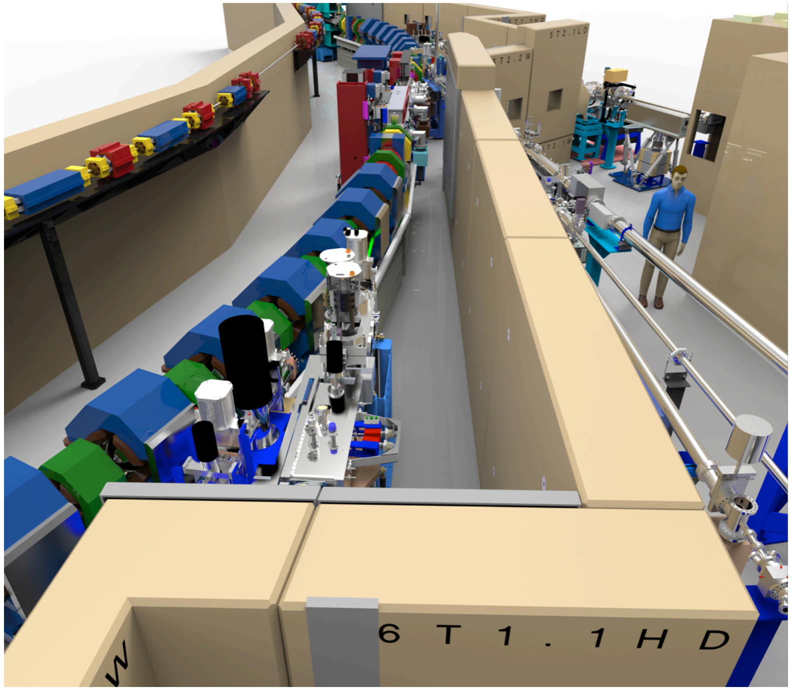
BERKELEY LAB

U.S. DEPARTMENT OF ENERGY | Office of Science

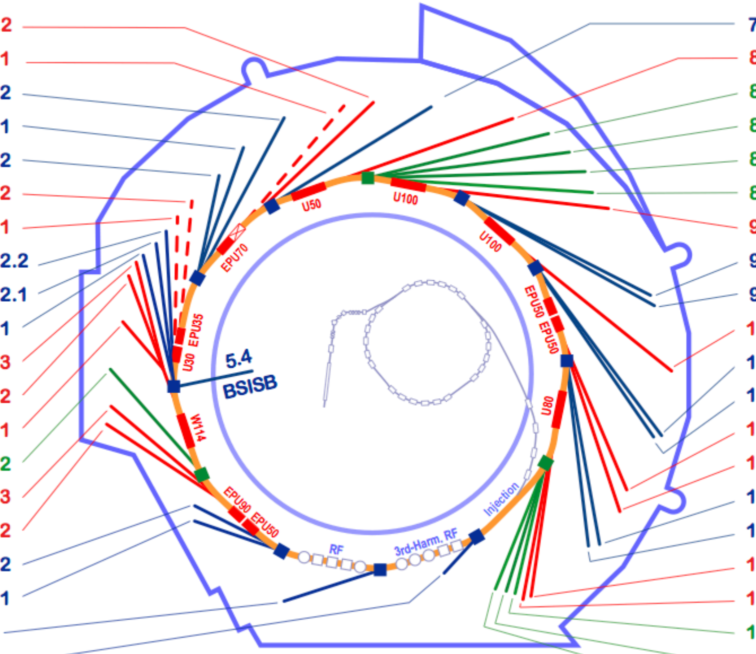
ALS-U ADVANCED LIGHT SOURCE

Outline

- **Motivation**
- **Overview of ALS-U**
- **Status**



ALS has been in operation since 1993



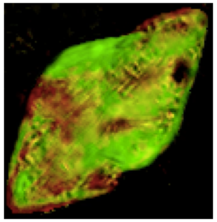
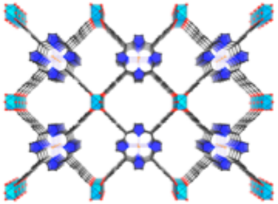
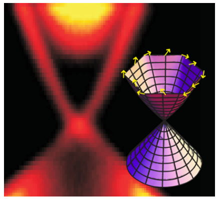
Surface, Materials Science (MAESTRO)	7.0.2
Coherent Scattering and Microscopy (COSMIC)	7.0.1
Calibration, Optics Testing, Spectroscopy	6.3.2
Magnetic Spectroscopy, Materials Science	6.3.1
X-Ray Microscopy	6.1.2
Energy Science (AMBER)	6.0.2
RIXS (QERLIN)	6.0.1
Polymer STXM	5.3.2.2
STXM	5.3.2.1
Research and Development	5.3.1
Macromolecular Crystallography	5.0.3
Macromolecular Crystallography	5.0.2
Macromolecular Crystallography	5.0.1
Macromolecular Crystallography	4.2.2
ARPES, RIXS (MERLIN)	4.0.3
Magnetic Spectroscopy and Scattering	4.0.2
General X-Ray Testing Station	3.3.2
Protein Footprinting	3.2.1
National Center for X-Ray Tomography	2.1
IR Spectromicroscopy	1.4

7.3.3	SAXS/WAXS
8.0.1	Surface, Materials Science
8.2.1	Macromolecular Crystallography
8.2.2	Macromolecular Crystallography
8.3.1	Macromolecular Crystallography
8.3.2	Tomography
9.0.2	Chemical Dynamics
9.3.1	AMO, Materials Science
9.3.2	Chemical, Materials Science
10.0.1	ARPES, SpinARPES
10.3.1	X-Ray Fluorescence
10.3.2	MicroXAS
11.0.1	PEEM3/Resonant Soft X-Ray Scattering
11.0.2	STXM, Ambient-Pressure XPS
11.3.1	Small-Molecule Crystallography
11.3.2	EUV Lithography, Mask Inspection
12.0.1	EUV Lithography
12.0.2	Coherent Soft X-Ray Science
12.2.2	High Pressure
12.3.1	Macromolecular Crystallography/Bio-SAXS
12.3.2	X-Ray Microdiffraction

KEY	— Operational	– – Under Construction
Insertion Device Beamlines	Bend Magnet Beamlines	Superbend Beamlines

- Highest-brightness undulators for SXRs
- Bend-magnet sources for broadband x-rays
- Superbend magnets for HXRs

Challenges at the frontier of matter and energy require better understanding of the functionality of complex, heterogeneous materials

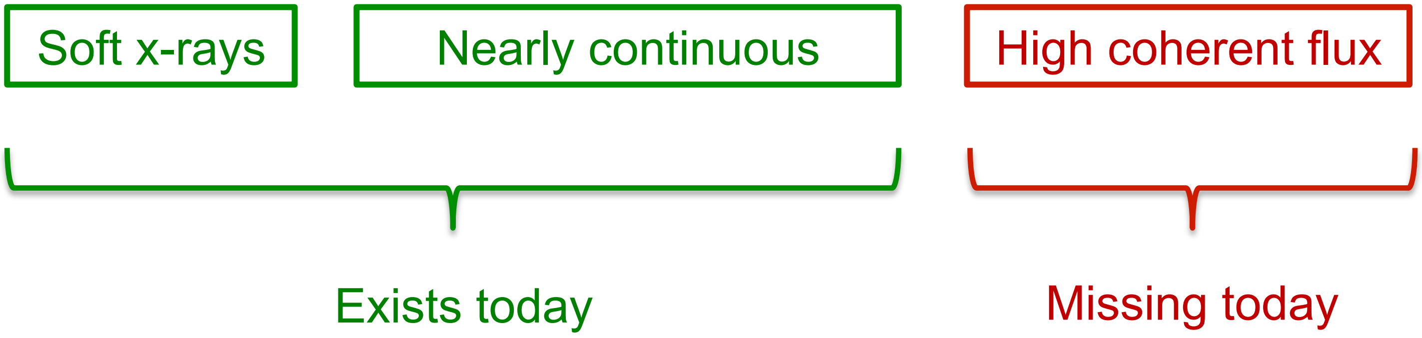
Transformative Opportunity	Example Application	Potential Societal Benefits
Understanding the Critical Roles of Heterogeneity	 Charge motion	energy storage
Mastering Hierarchical Architectures	 Controlling chemistry	chemical catalytic reactors, solar fuel production, water purification
Harnessing Coherence in Light and Matter	 Topological spin and quantum matter	ultralow-power computing, new classes of sensors, spin-based devices

Requires new and improved probes

DOE/BES recognizes the need for a next-generation soft x-ray light source with the following properties:

- **Soft x-ray light**, which has the appropriate energy to interact strongly with the electrons that determine the *chemical*, *electronic*, and *magnetic* properties of materials, and

- **High coherent flux delivered in a nearly continuous wave**, which is necessary to resolve *nanometer-scale* features and interactions and which allows *real-time observation* of chemical processes as they evolve and materials as they function.



Soft x-rays

Nearly continuous

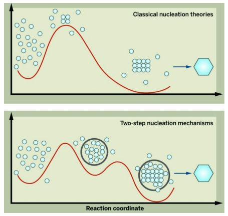
High coherent flux

Exists today

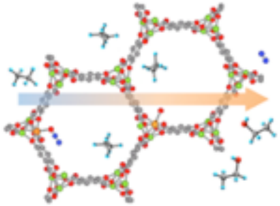
Missing today

Probing processes at natural length and time scales

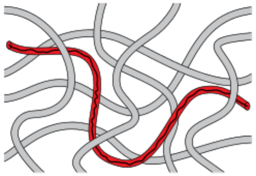
Nucleation kinetics
10.1126/science.
1230915



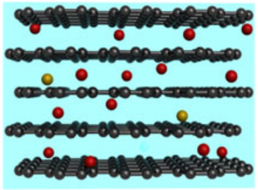
Catalytic kinetics
10.1038/nchem.1956



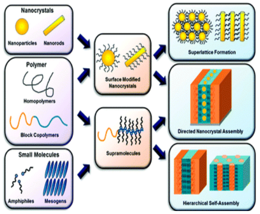
Polymer reptation
Wikipedia

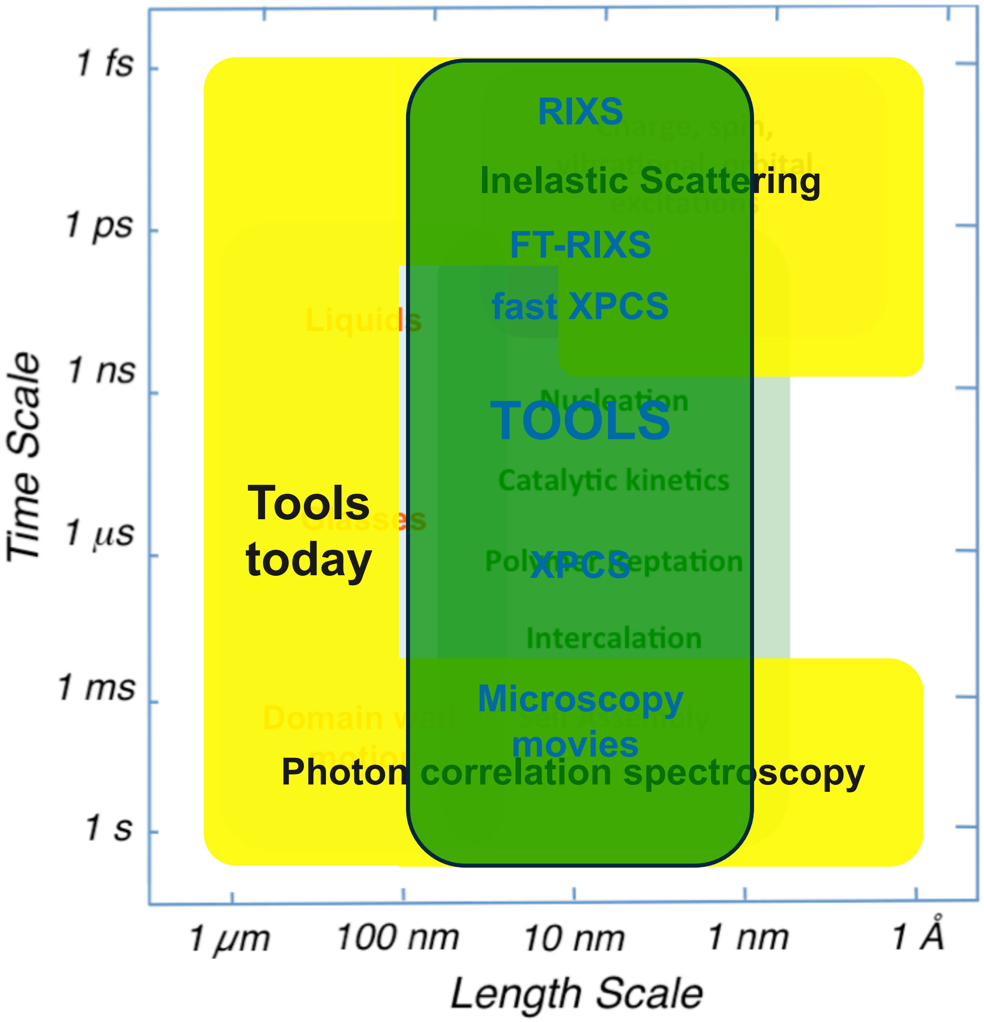


Intercalation kinetics
10.1038/Fncomms6716



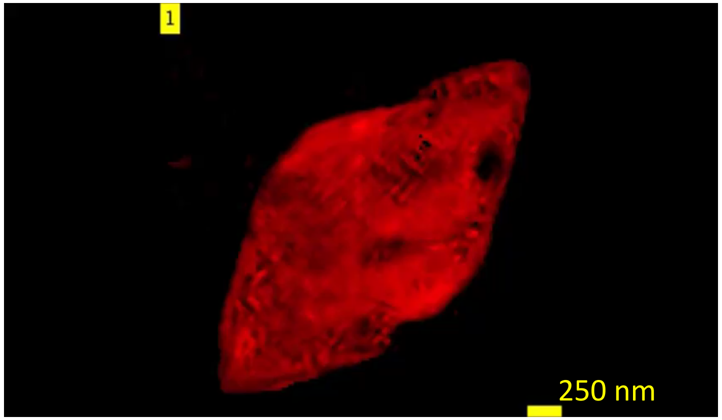
Self assembly
T. Xu, LBNL





High soft x-ray coherent flux allows probing the nanoscale chemical and material kinetics over an unprecedented temporal range

Map spatiotemporal chemical kinetics in heterogeneous media at ~kHz frame rate

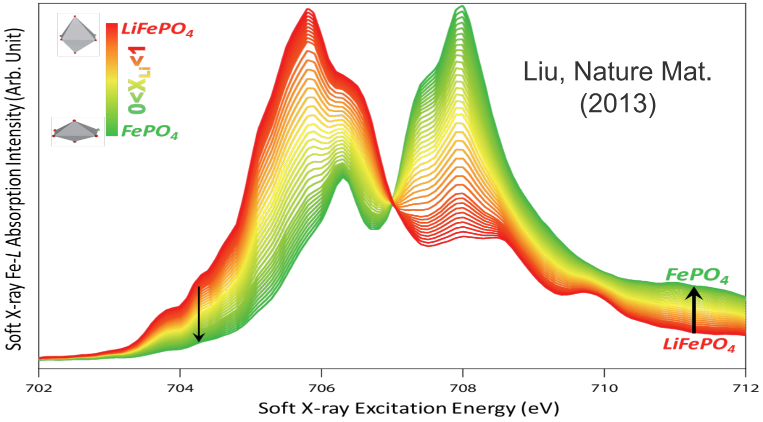


“X-ray movies”

Lim, Science 2016

Combine Fe oxidation state contrast with ptychography to map nanoscale function in a grain of Li_xFePO_4

(2D movie; ~15 nm resolution;
2 energies; 30 sec/frame)



Liu, Nature Mat. (2013)

	30 nm	10 nm	3 nm
ALS	180 s	4 hours	23 days
ALS-U	1.8 s	144 s	5 hours

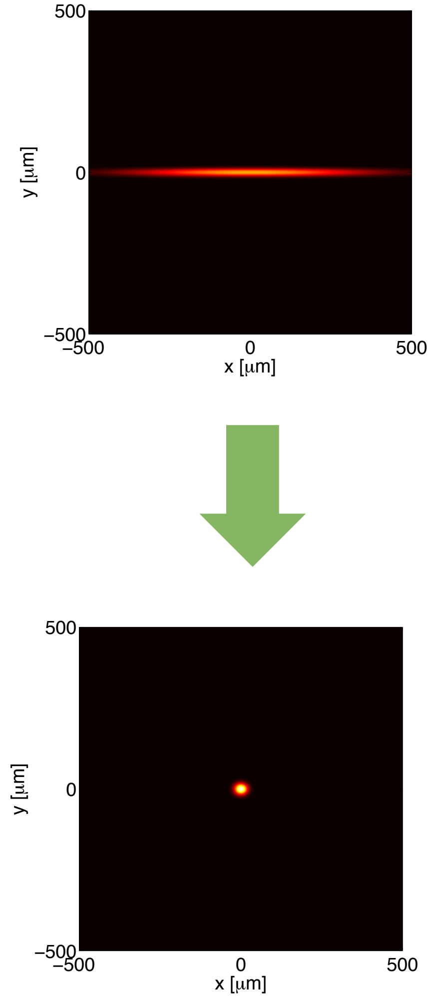
X-ray exposure time required to image this particle in 3D with full spectral coverage

ALS-U will revolutionize our ability to observe in real time the impact of interfaces and defects on nanoscale material and chemical kinetics

Advanced Light Source Upgrade

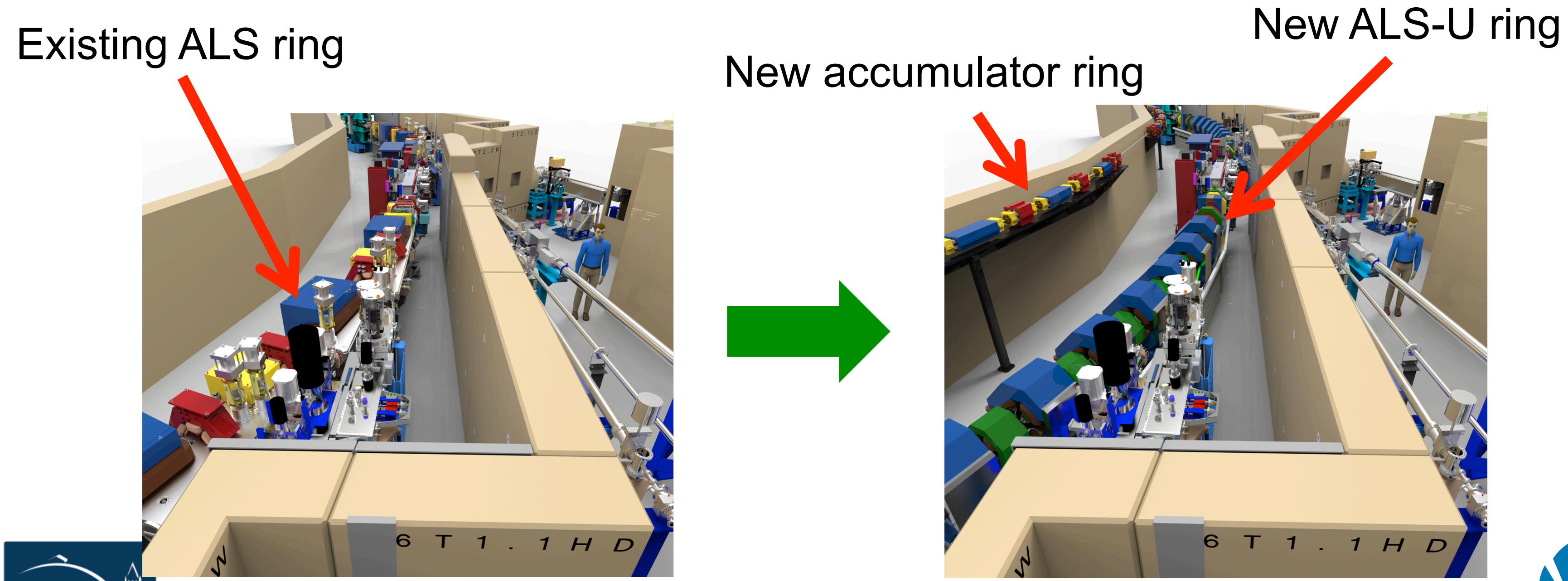
- The ALS-U design is based on the multibend achromat lattice that is being adopted by many new and upgraded facilities.

- High coherent flux will make it possible to resolve nanometer-scale features and interactions and will allow real-time observation of chemical processes.

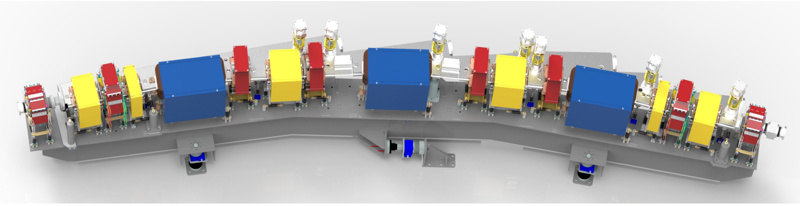


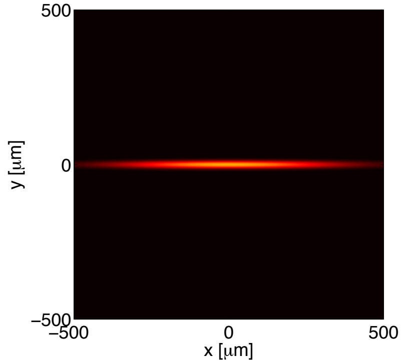
Scope of ALS-U

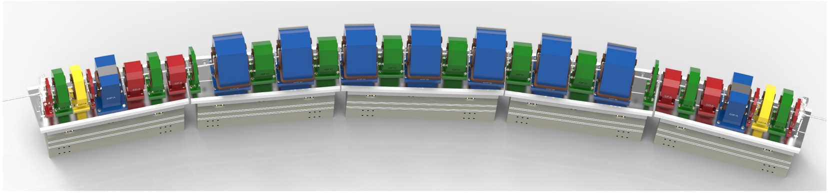
1. **Replacement** of the existing triple-bend achromat storage ring with a new, high-performance storage ring based on a multi-bend achromat.
2. **Addition** of a low-emittance, full-energy accumulator ring in the existing storage-ring tunnel to enable on-axis, swap-out injection using fast magnets.
3. **Upgrade** of the optics on existing beamlines and realignment or relocation of beamlines where necessary.
4. **Addition** of three new undulator beamlines that are optimized for novel science made possible by the beam's high coherent flux.

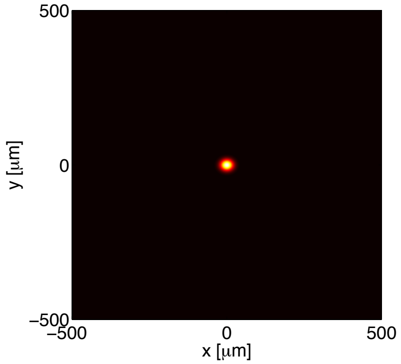


ALS and ALS-U in numbers









Parameter	Units	ALS	ALS-U
Electron energy	GeV	1.9	2.0
Horiz. emittance	pm	2000	~50
Vert. emittance	pm	30	~50
Beamsize @ ID center (σ_x/σ_y)	mm	251 / 9	<10 / <10
Beamsize @ bend (σ_x/σ_y)	mm	40 / 7	<5 / <7
bunch length (FWHM)	ps	60-70 (harmonic cavity)	120-200 (harmonic cavity)
RF frequency	MHz	500	500
Circumference	m	196.8	~196.5

ALS-U: Designed to be the world's highest coherent flux soft x-ray synchrotron light source

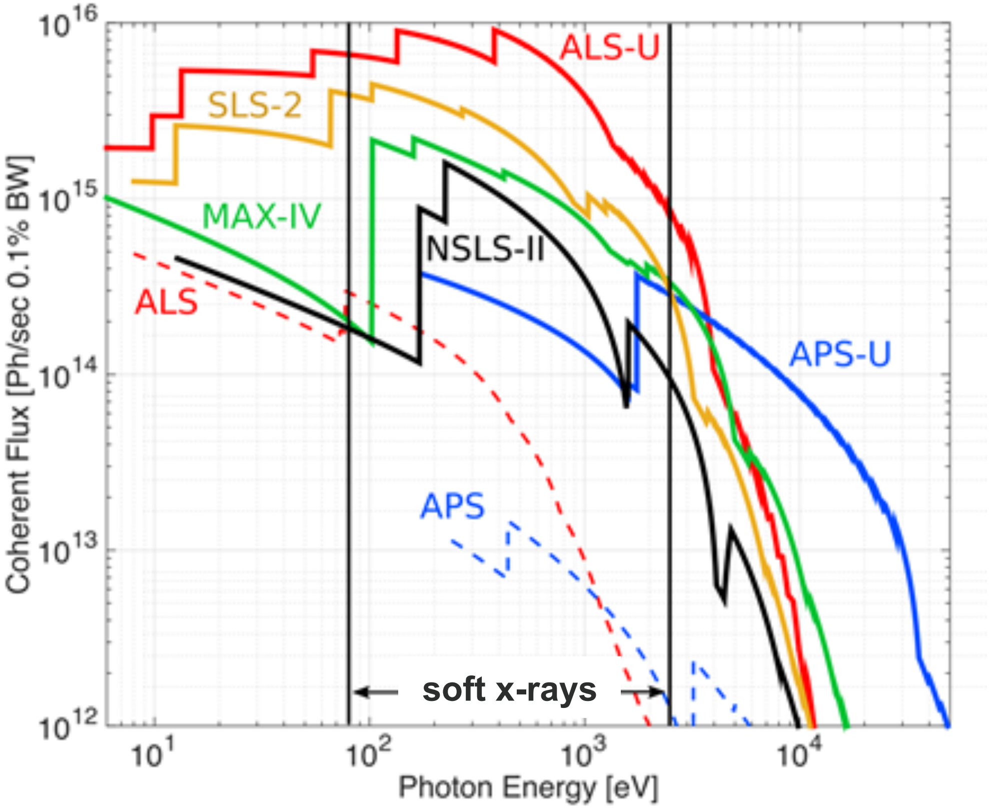
Reasons

1. **Optimal beam energy (2 GeV)**
   - Highest flux
   - Minimizes beamline heating

2. **Beams that are nearly fully coherent in transverse direction**
   - MBA technology with swap-out injection allows ~50-pm-rad emittance round beams

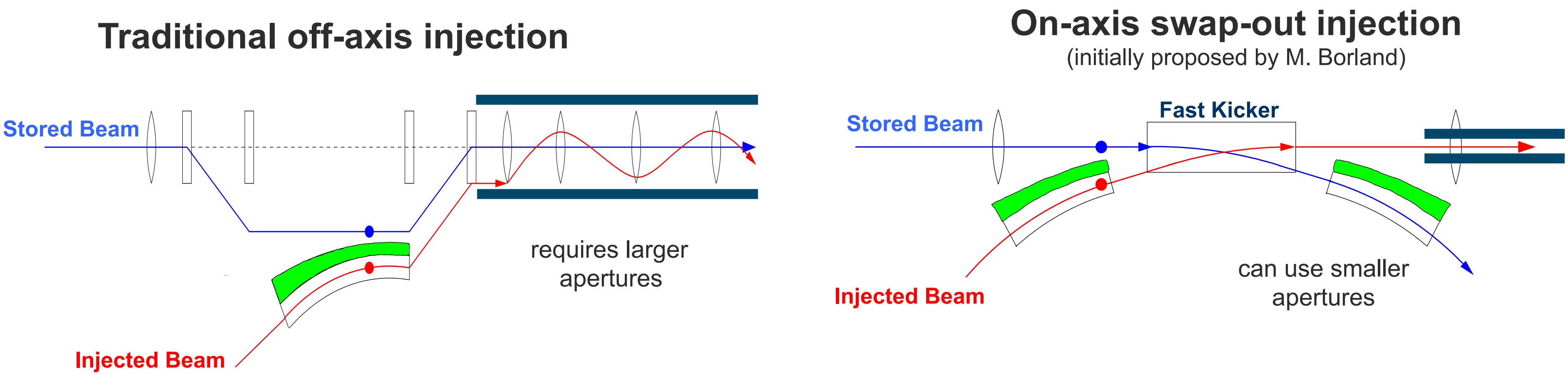
3. **Optimal insertion devices**
   - Swap-out injection permits small, round (4-6 mm diameter) vacuum apertures

Coherent Flux



ALS-U will near the fundamental limit of what is possible with any currently envisioned storage ring technology

Swap-out with a full-energy accumulator



Swap-out enables:

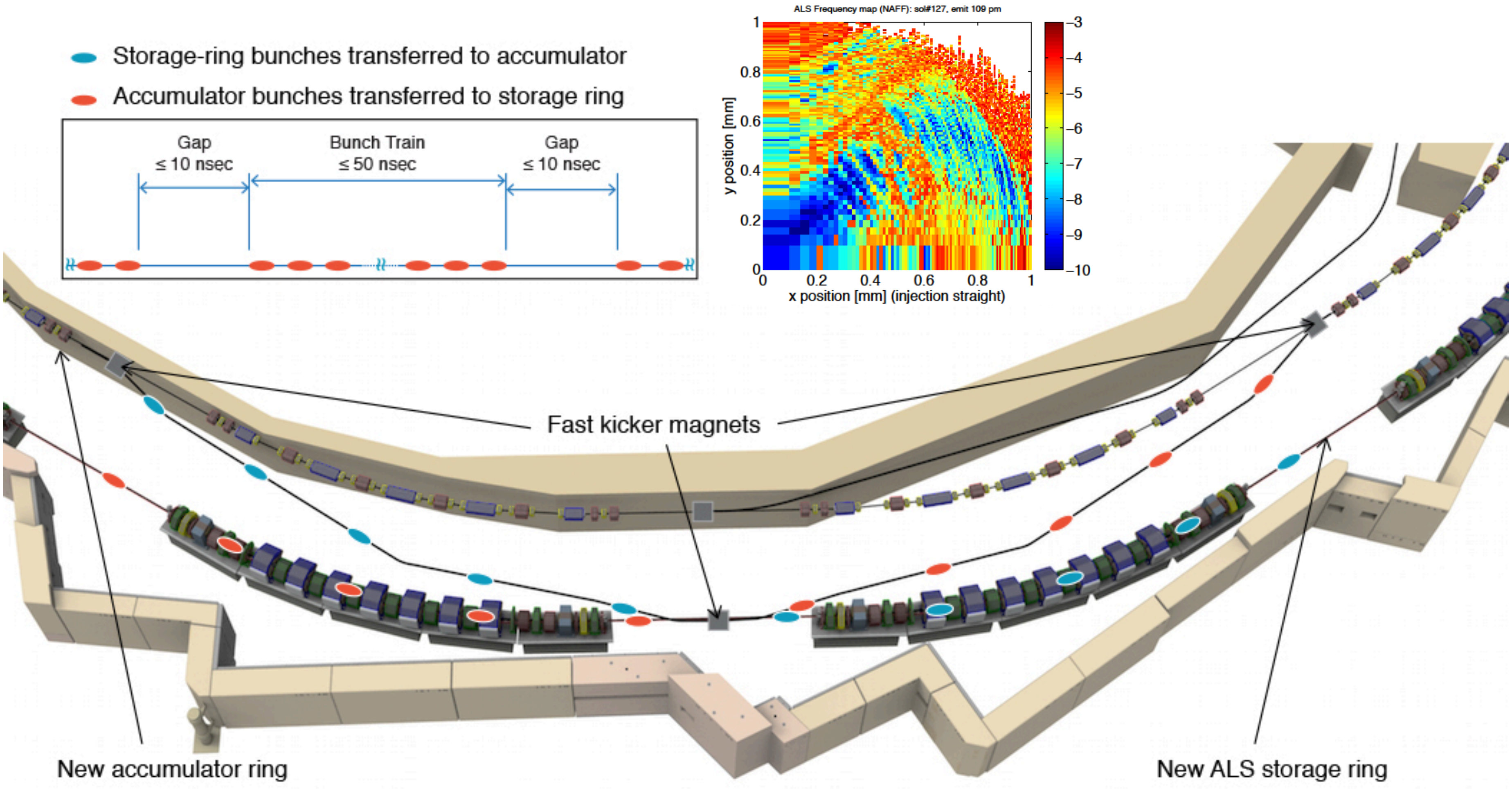
- Stronger-focusing MBA lattices with smaller dynamic apertures
- Round beams - more useful shape and reduced emittance growth
- Vacuum chambers with small round apertures → Improved undulator performance

Only ALS-U and APS-U plan to include swap-out

Swap-out with full energy accumulator enables:

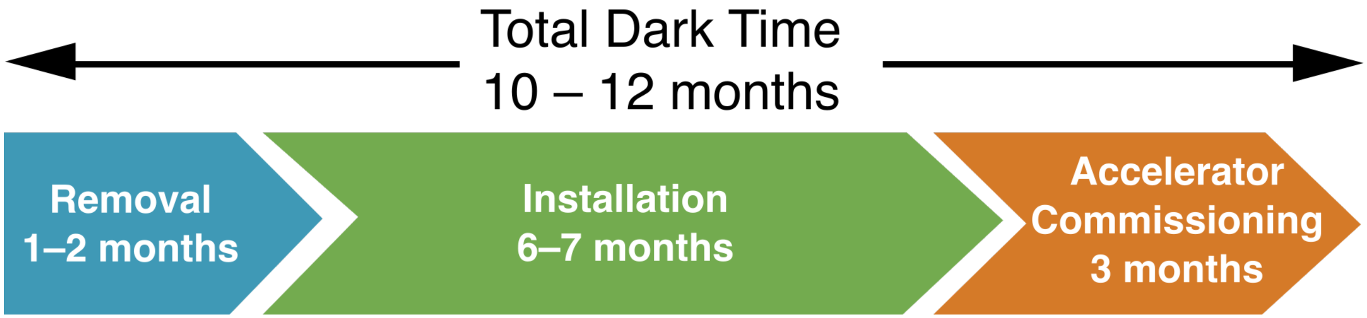
- Bunch train swap-out and recovery of the stored beam current
  - Lower demand on the injector
  - Very small (~nm) injected emittance
  - More flexibility in fill patterns

Swapping accumulator and storage ring beams



Swap-out injection was first proposed by M. Borland for possible APS upgrades

Plan to minimize interruption of science program



Total Dark Time
10 – 12 months

Removal
1–2 months

Installation
6–7 months

Accelerator
Commissioning
3 months

Removal and Installation (7-9 months)

- Extensive early planning , including with experts in lean design, logistics, and construction

Accelerator Commissioning (3 months)

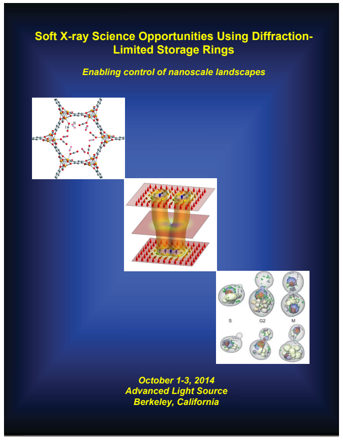
Developing fast, automated, beam-based commissioning techniques now

- >50% of beamlines will be ready at end of accelerator commissioning
- The remainder of beamlines will be ready within 6 months of the end of accelerator commissioning

Jim Haslam
Installation and
Removal Lead

ALS-U Timeline and Status

Jul 2013	BESAC Subcommittee on Future X-ray Light Sources: “The Office of Basic Energy Sciences should ensure that U.S. **storage ring** x-ray sources reclaim their world leadership position.”
Oct, 2014	*Workshop on Soft X-ray Science Opportunities using Diffraction-Limited Storage Rings, LBNL* – result presented at Feb 2015 BESAC Meeting
Since FY14	Received funding from LBNL for R&D as well as pre-project development. In FY16 received funding from BES for Research and Development for the Advanced Light Source Upgrade
Jun 2016	BESAC Prioritization Panel grades ALS-U as “Absolutely Central” to contribute to world leading science and as “Ready to Initiate Construction”
Sep 2016	ALS-U receives approval of Mission Need (CD-0) from DOE/BES



Soft X-ray Science Opportunities Using Diffraction-Limited Storage Rings

Enabling control of nanoscale landscapes

October 1-3, 2014
Advanced Light Source
Berkeley, California

Technical challenges and mitigation strategies have been identified and separated into two categories

Category 1. Risks that are typical of MBA designs and are similar for all new and upgrade projects that employ MBAs, such as:

- Small (~20 mm) aperture NEG-coated vacuum chambers
- Tightly packed MBA lattice

Category 2. Those that are specific to ALS-U related to optimizing a machine for soft x-rays with the resulting lower electron beam energy, such as:

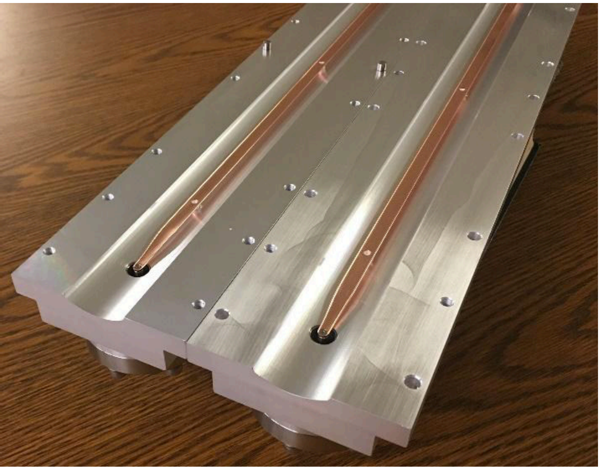
- Swap-out injection
- Emittance increase due to intrabeam scattering
- Very small (4 to 6 mm) aperture NEG-coated vacuum chambers

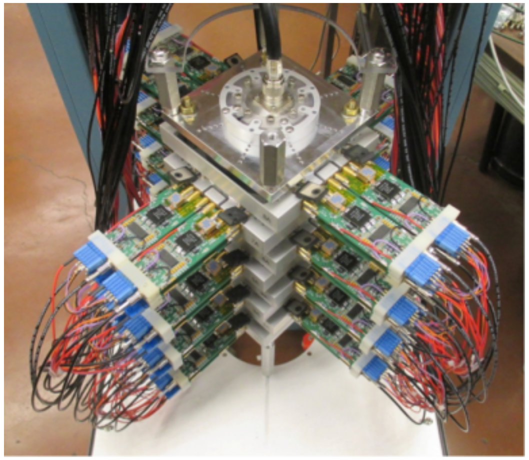
Substantial R&D progress mitigating technical challenges specific to ALS-U

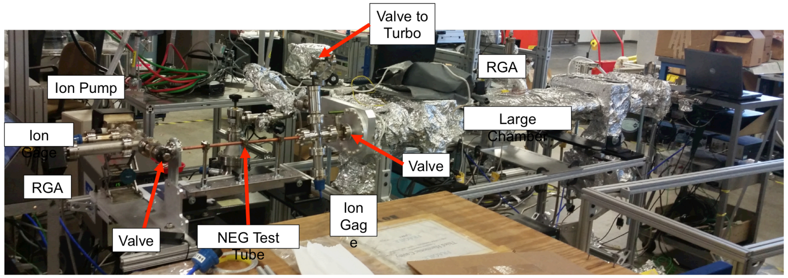
3 years of R&D – initially LBNL funded, later received $5.8M from BES

Risks that have been or are in the process of being mitigated:

- NEG-coating process has potential for smaller apertures than prior art
- Fast kickers/pulsers with necessary parameters for swap-out can be built
- Bunch-lengthening factors achievable with fill patterns for swap-out
- Minimize thermal distortion of coherence-preserving optics
- Fast automated commissioning algorithms



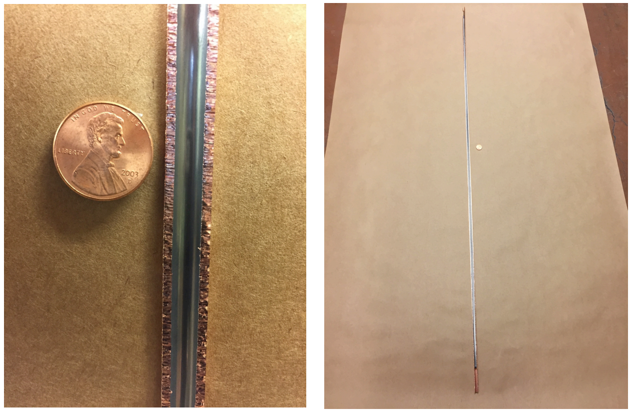




Left: Prototype Stripline kicker. Middle: Full inductive adder. Right: NEG coating activation test stand.

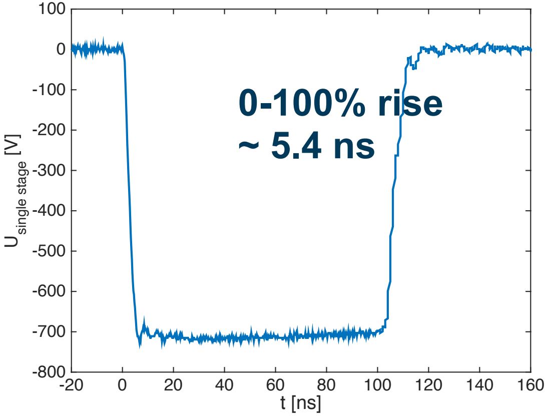
Substantial R&D progress to date on mitigating technical challenges specific to ALS-U

Very small NEG coated vacuum chambers



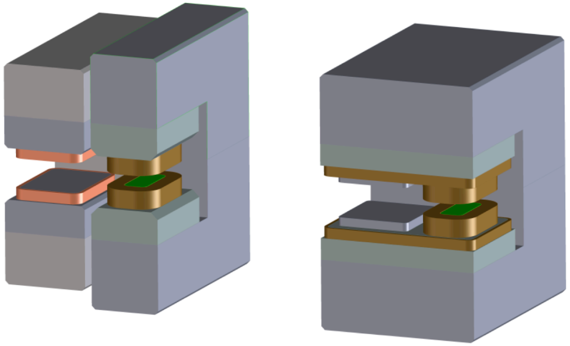
Coated 6 mm chamber (world record)

On-axis Injection – Fast pulsed magnets



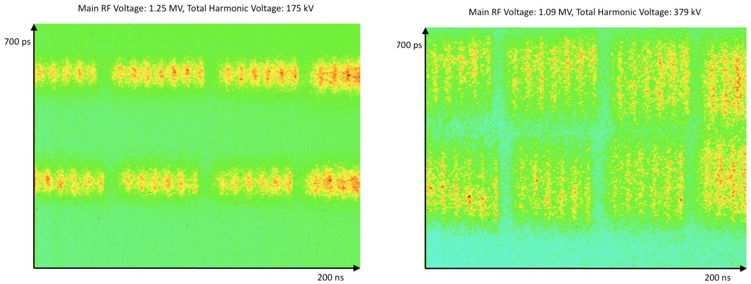
Single stage of inductive adder achieves 5 ns rise (7 ns needed)

Magnets – SR Production



Developing Superbend options

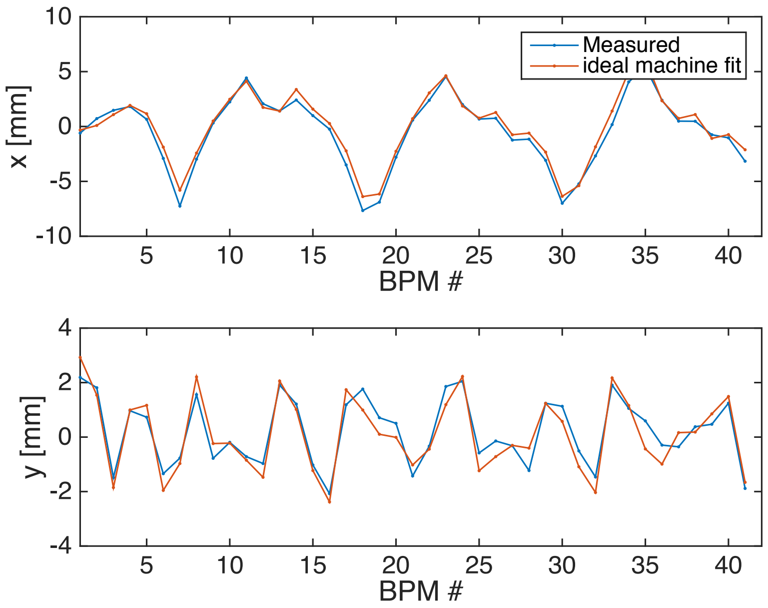
Harmonic Cavities - Transients



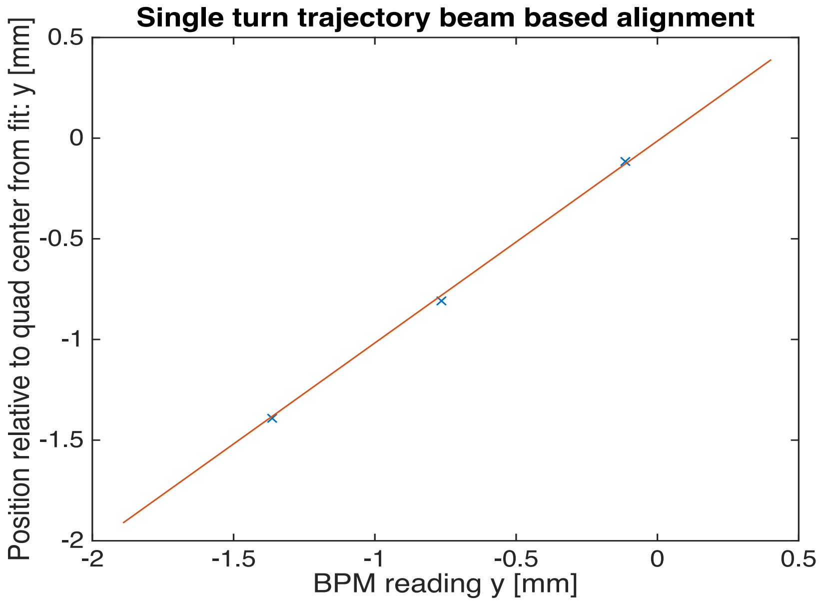
Achieved needed bunch lengthening with ALS-U bunch trains in ALS (3HC)

Beam based alignment using turn-by-turn BPMs

- Demonstrated trajectory correction and ability to do better than 100 micron accuracy beam-based alignment without requiring stored beam.



Intentionally offset first turn trajectory of injected beam in the ALS and trajectory fits using the ideal machine model.



Beam based alignment measurement using only first turn trajectory measurements. Result agrees within 50 microns with stored beam measurements.

Successful initial tests of automated commissioning and getting to stored beam

Motivation:

- Traditional **manual** machine commissioning is slow and will be more challenging for the smaller dynamic aperture MBAs.
- New BPMs and algorithms offer the opportunity to largely automate and shorten the time to commissioning

Experimental test setup:

- Developed trajectory response matrix and correction code
  - Configurable number of turns, correctors, and singular values.
- Test example with all correctors off – beam makes only one turn due to a single badly aligned sextupole

Result of test:

- **Correction sufficient after 3 injection shots to store beam!**
  - Residual closed orbit error about 1 mm peak

Led by C. Steier

Update on ALS-U Optics: Issues and R&D

ALS → ALS-U **horizontal source** ~25× smaller: **power density** is higher

Optics Quality: A much higher quality manufacturing needed to preserve wavefront

- 1 manufacturer worldwide working at the tolerances necessary
  - *mainly an issue of qualification of optical metrology*

Vibration: A lower level of (horizontal) vibration is required for stable beams

- Water-induced vibration is the main issue
- Developed sophisticated fluid dynamics modeling capability
- Comparing theory to bench-test models of cooled mirrors

Mirror Cooling: ALS-U requires much better cooling to preserve mirror shapes

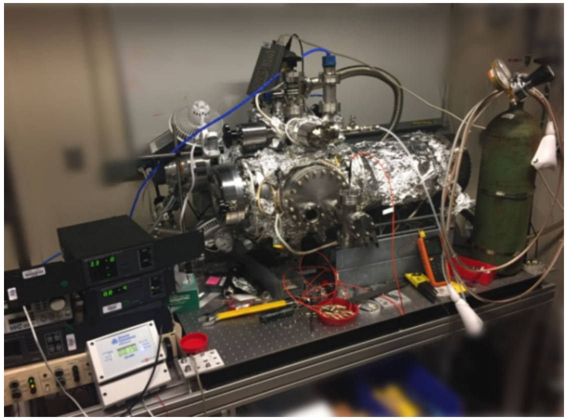
- Optimized, water-cooled Si optics will work at present ALS undulator power levels (FEA)
- LN2-cooled optics can meet the slope error tolerance for the most powerful undulators.
  - Introduces issues of stress-induced shape change and contamination

Carbon Contamination: Much lower levels of carbon are needed

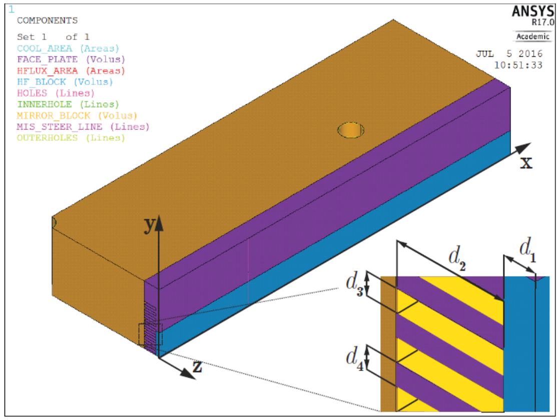
- Carbon is a phase shifter and beam attenuator: effect is like a physical surface bump
  - Potentially very damaging to the preservation of wavefront quality
- Avoidance requires much better UHV conditions, and in situ plasma cleaning

Led by K. Goldberg

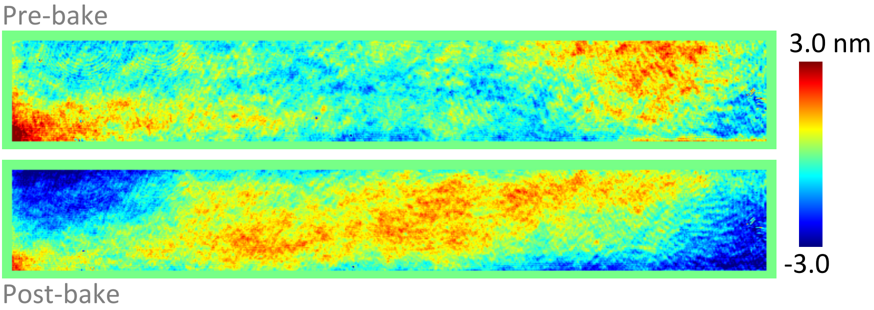
Optics Challenges: ability to preserve coherent wavefront



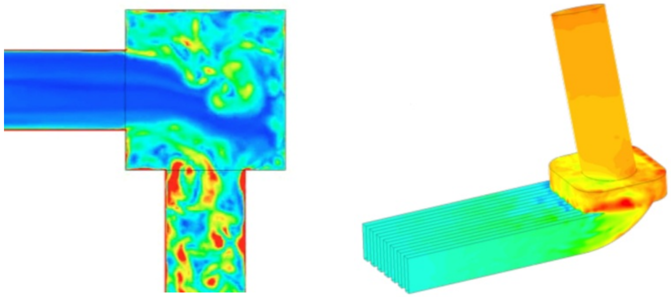
Understanding how to remove/prevent carbon



Understanding the dynamic response of mirrors to changing power density, e.g. ID polarization changing

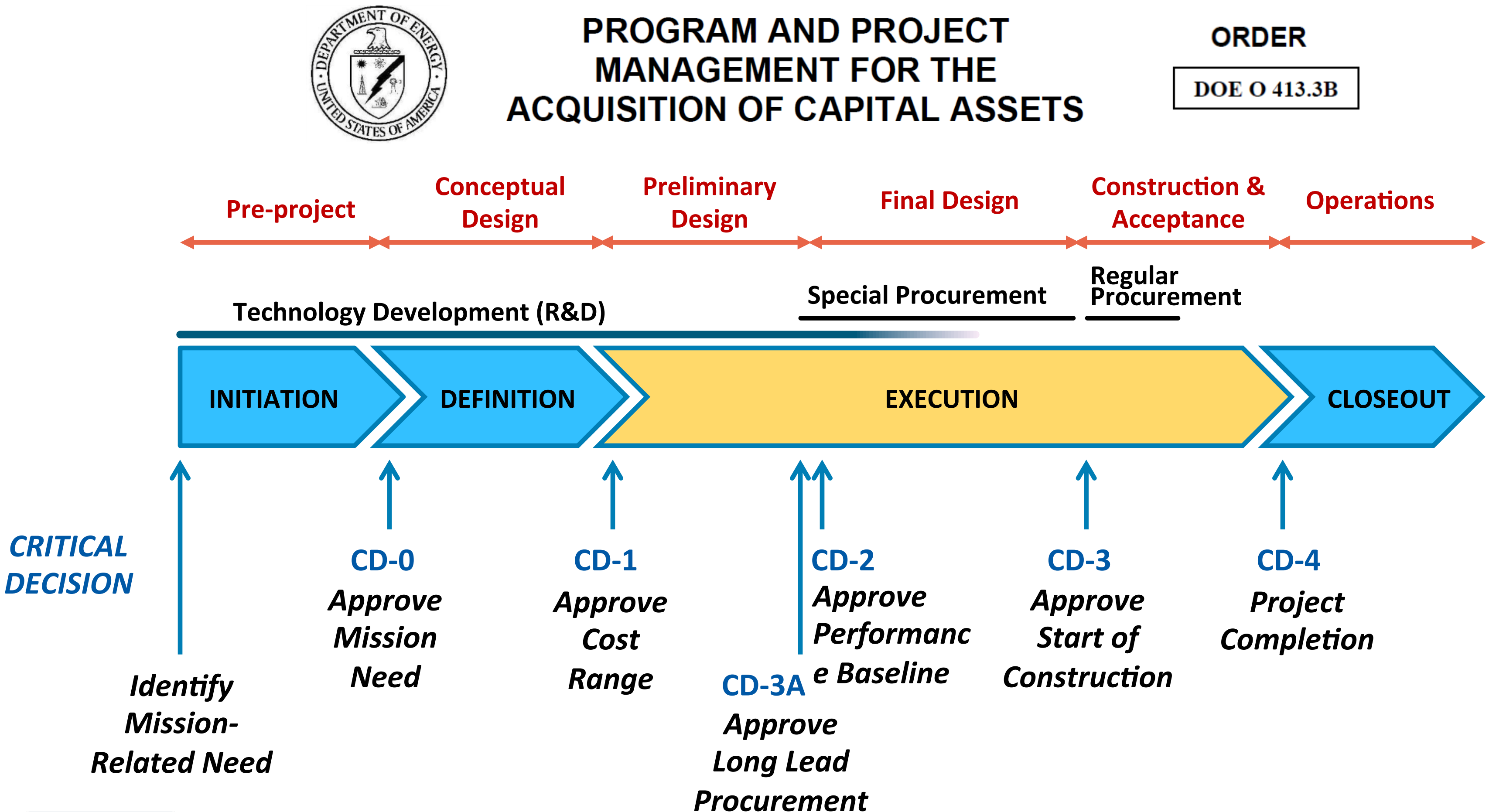


Si mirror shape changes induced by mirror baking



Water-cooled-mirror fluid dynamics simulations

CD-0 means the project has started!



PROGRAM AND PROJECT MANAGEMENT FOR THE ACQUISITION OF CAPITAL ASSETS

ORDER

DOE O 413.3B

ALS-U core team

Steve Kevan
Science Lead

David Robin
Project Director

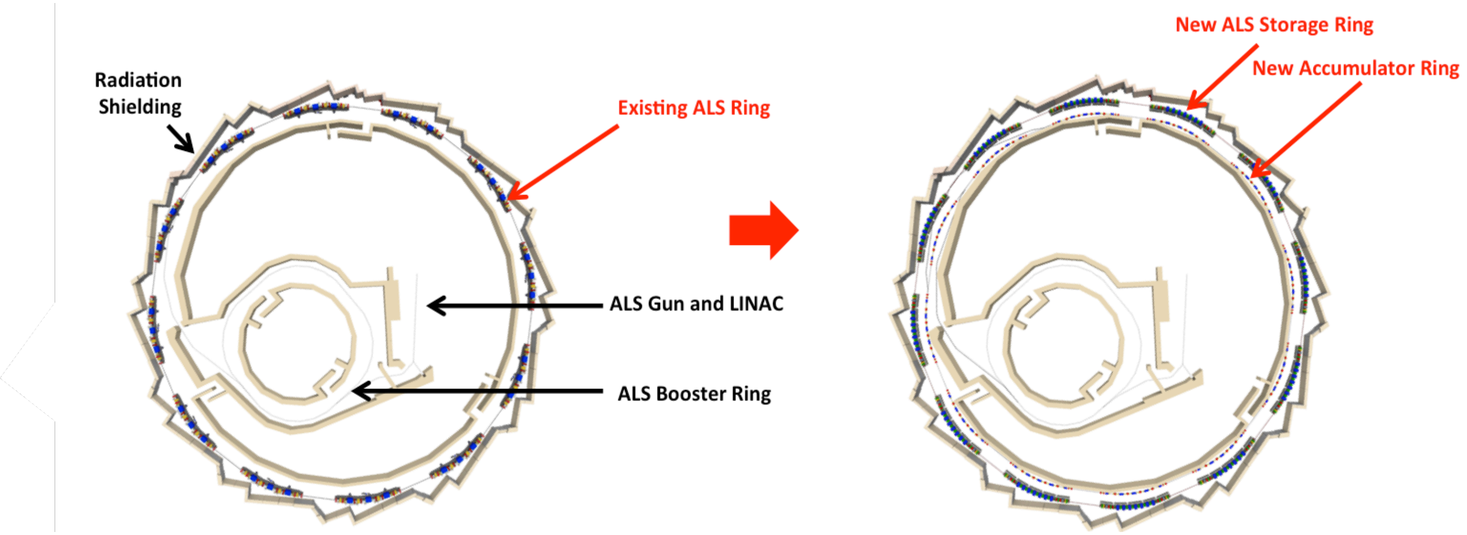
Ken Chow
Project Manager

Christoph Steier
Accelerator Systems Lead

Howard Padmore
Experimental Systems Lead

Jim Haslam
Installation and Removal Lead

Very excited that ALS-U has begun



ALS-U will meet a key BES/DOE need by providing world-leading soft x-ray beams with high coherent flux to enable cutting-edge science.

- Laboratory Director has named ALS-U the top priority project for Berkeley Laboratory
- Technical issues and risks are identified, and R&D is underway to mitigate significant technical risks and uncertainties.
- More in talks by

  Marco Venturini (Beam Physics Challenges) and

  Stefano DeSantis (Injection/extraction kickers and harmonic cavities for ALS-U)

Thank you

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U.S. DEPARTMENT OF ENERGY | Office of Science

ALS-U
ADVANCED LIGHT SOURCE