ALS User Forum on the ALS-U Project Beamlines

February 25, 2019

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U.S. DEPARTMENT OF ENERGY | Office of Science

ALS ADVANCED LIGHT SOURCE

Agenda

- **ALS-U beamline selection process and the path to ALS renewal**
  - David Robin (ALS-U Project Director)
  - Andreas Scholl (Interim ALS Science Deputy)
- **Science at the new and upgraded ID beamlines**
  - COSMIC upgrade, David Shapiro (ALS) and Will Chueh (Stanford)
  - MAESTRO upgrade, Eli Rotenberg (ALS) and Jyoti Katoch (Carnegie Mellon)
  - New tender x-ray beamline, Chenhui Zhu (ALS) and Pupa Gilbert (University of Wisconsin–Madison)
  - New soft x-ray beamline, Sujoy Roy (ALS) and Alex Frano (UCSD)
- **Q&A**

ALS-U beamline selection process and the path to ALS renewal

Dave Robin
ALS-U Project Director

Andreas Scholl
Interim ALS Science Deputy

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ALS-U: Enabling the ALS's global leadership in soft x-ray science

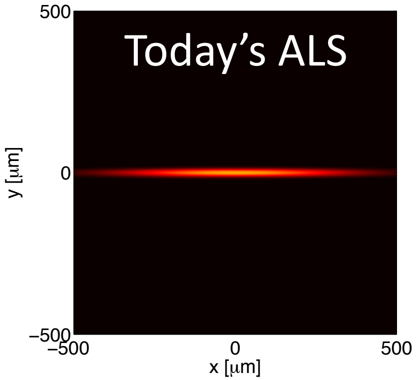
Features

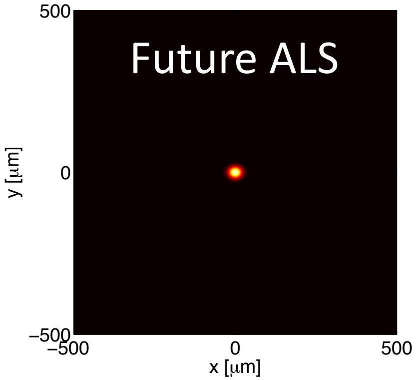
- World-leading soft x-ray brightness and capabilities
- More than 100x increase in soft x-ray brightness and coherent flux compared with today's ALS
- Excellent IR and hard x-ray capabilities

Impact

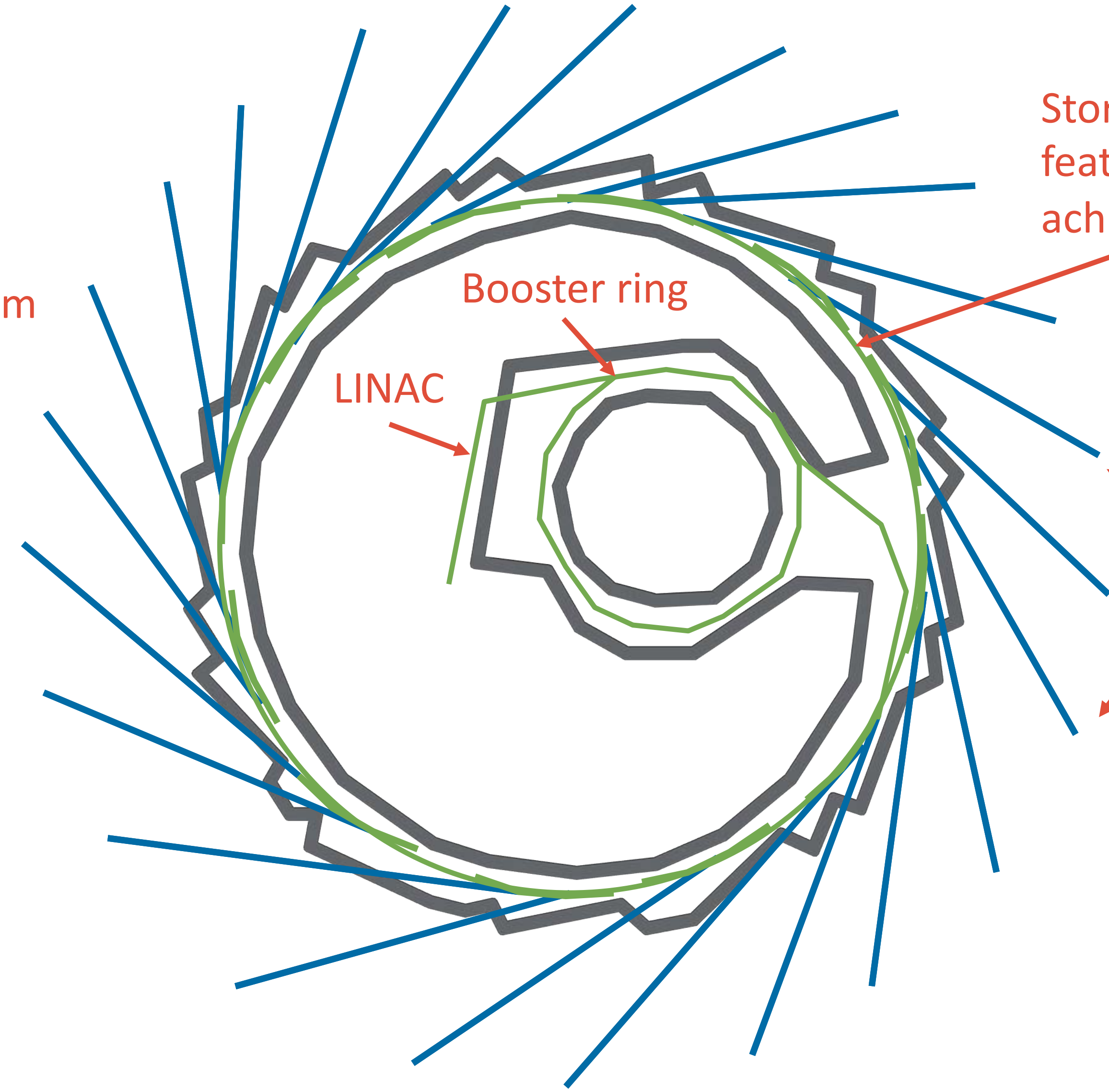
- Enable scientific advances in a diverse range of fields, improving our economy, healthcare, and national security
- Continue the ALS tradition of serving a large and scientifically diverse user community

Electron Beam Profile Comparison

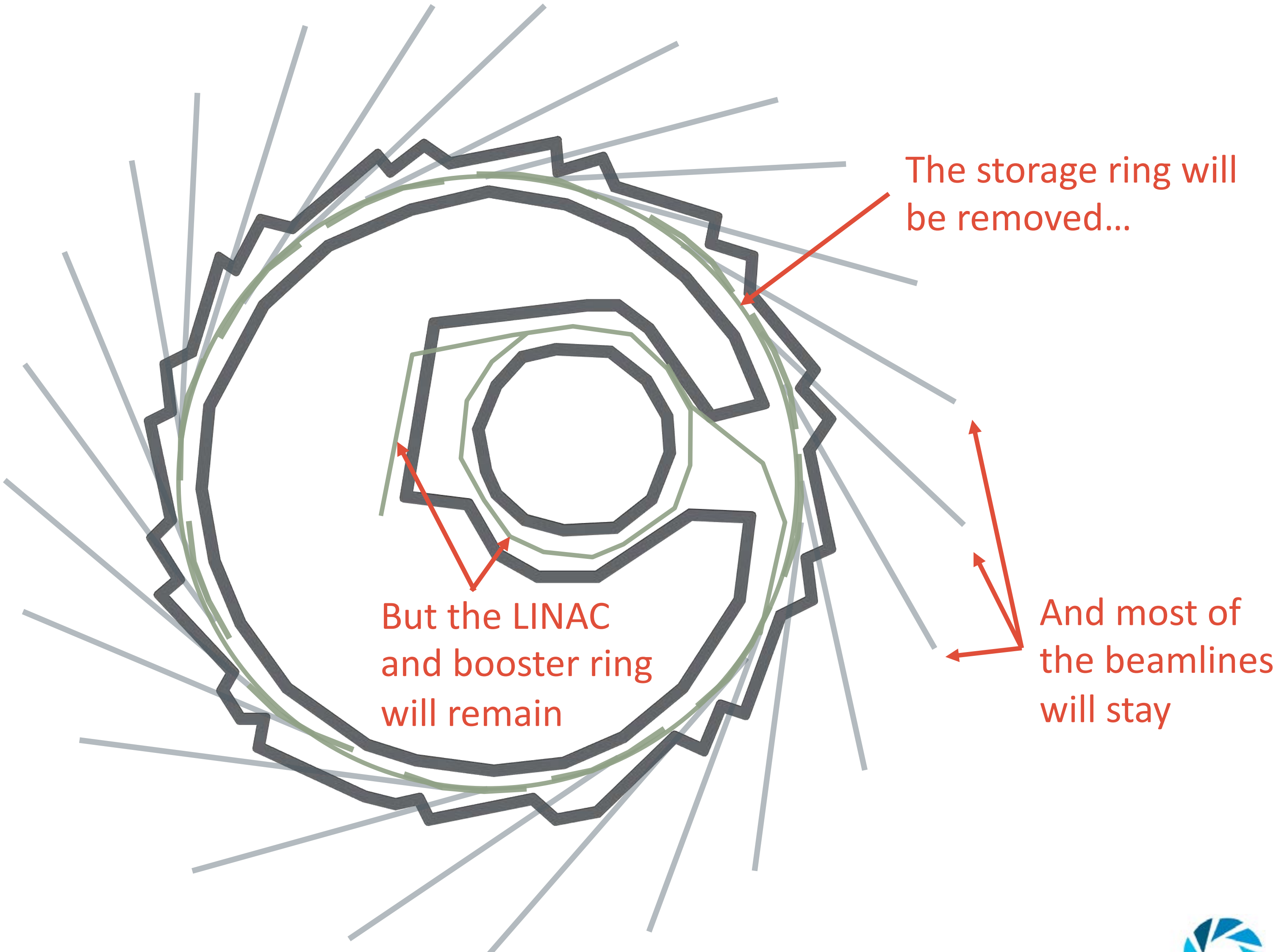




The ALS today has…



During the construction phase of the project…



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During the construction phase of the project…

A small number of new soft x-ray insertion-device beamlines will be added

Some new insertion devices will be added to the ring

And a small number of soft x-ray insertion-device beamlines will be upgraded

A new storage ring will be built, based on a 9-bend achromat

And a second concentric “accumulator” ring will be added

Bend and superbend beamlines will be realigned

= beamline included in ALS-U project

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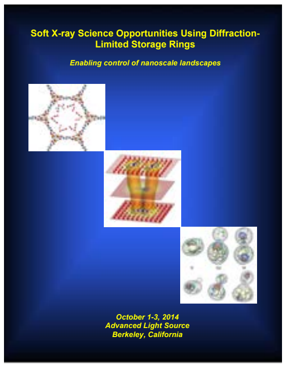
User community engagement in ALS-U beamline planning

Workshops



Oct. 2014

Jan. 2017

User Meetings

User Forums

Topical Cross-Cutting Reviews & Workshops

Web Forms

Informal Conversations

Examples of community input

- "Current-day RIXS experiments will highly profit from the smaller beam provided by ALS-U since it enables a smaller spot size on the sample..."

- "...developing a technique capable of simultaneously probing multiple order parameters...and with spatial resolution for inhomogeneous sample would lead to major advances in the understanding and development of new materials."

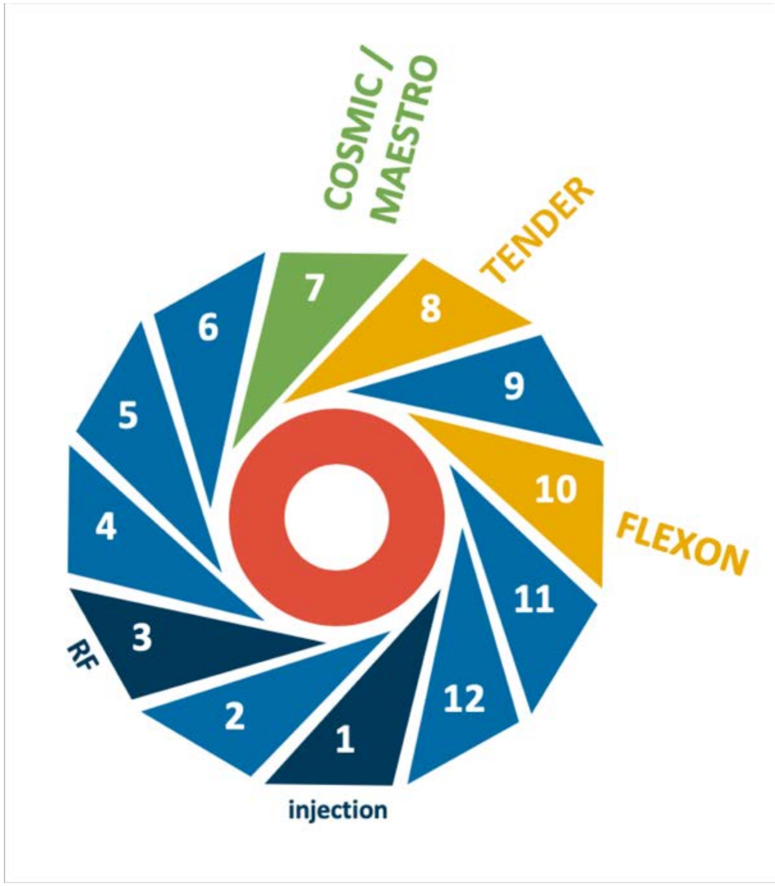
Prioritization criteria

- Scientific importance
- Relevance of ALS-U characteristics and potential world leadership
- Strength of the relevant user community and expected productivity
- Overall approach, feasibility, R&D activities, and fit to project resources

Decision-making process

- 16-month process
- User community and ALS staff input was evaluated, then synthesized into several beamline scenarios by a working group of ALS staff
- External committees (ALS and ALS-U advisory committees, a steering committee, and an ad-hoc evaluation committee) reviewed the scenarios
- Ad-hoc committee made a recommendation
- ALS-U Project Director made the final decision

ALS-U upgraded and new beamlines at the ALS

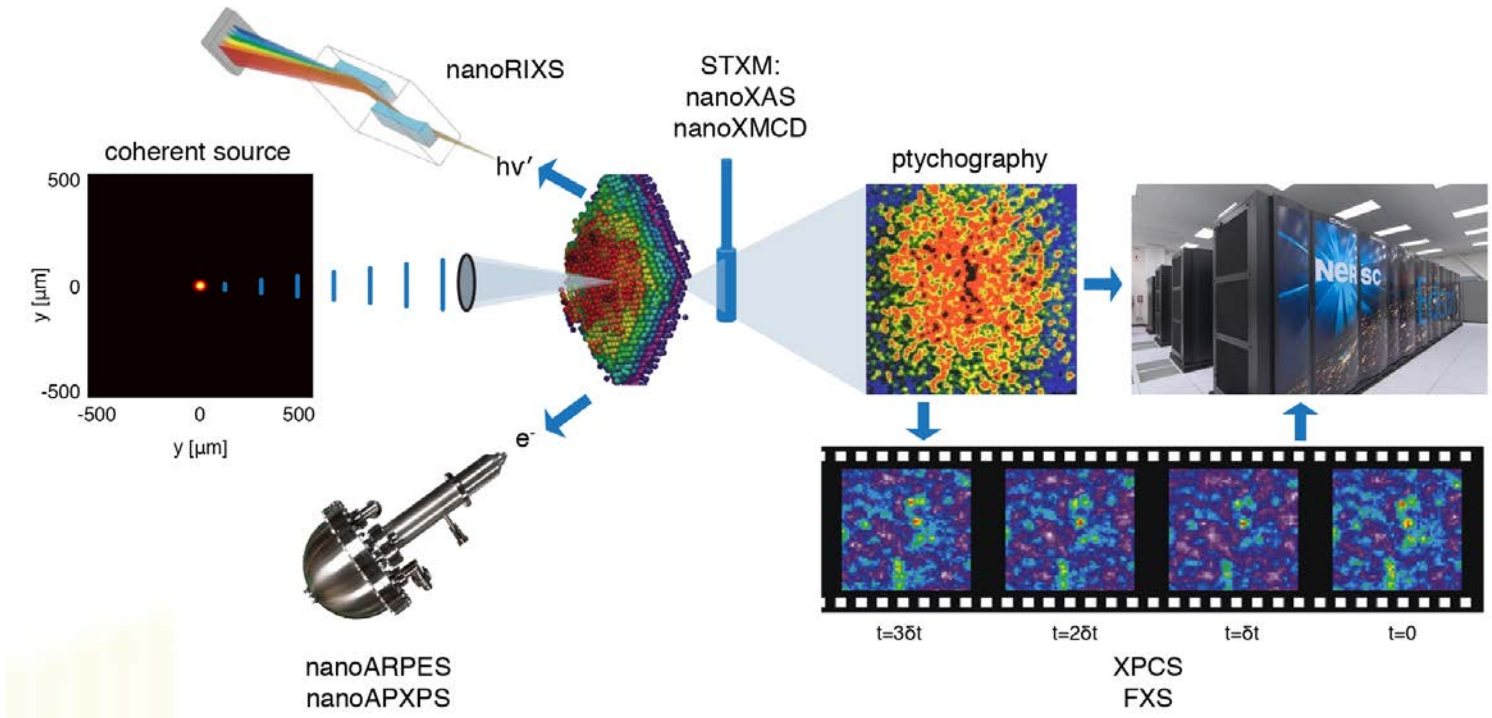


Sector 7: Upgrade MAESTRO and COSMIC (COSMIC XPCS to move to Sector 10)

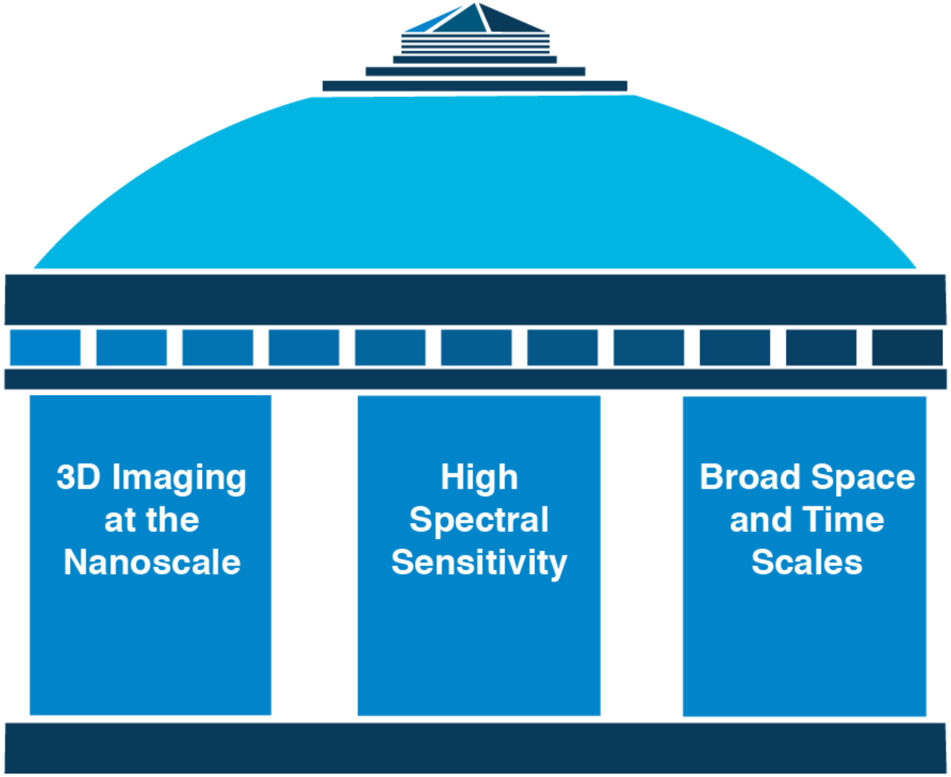
Sector 8: Build a new tender x-ray beamline featuring STXM and coherent scattering

Sector 10: Build a new soft x-ray beamline featuring XPCS, nRSoXS, and nRIXS

Technique toolbox of the upgraded ALS



The capabilities imparted by the ALS-U project will provide the foundation for new ALS science



Crosscutting challenges addressed by the future ALS

Spectral Mapping of Nano-Objects

Designing Functional Interfaces

Harnessing Entropy for Material and Chemical Design

Measuring & Manipulating Nanoscale Currents & Flows

Materials Chemistry and Physics in Confined Spaces

ABBREVIATED VERSION

ALS-U:

Solving Scientific Challenges with Coherent Soft X-Rays

Workshop report on early science enabled by the Advanced Light Source Upgrade

WORKSHOP CHAIR: Steve Kevan
ALS-U PROJECT DIRECTOR: David Robin
ALS DIRECTOR: Roger Falcone

BREAKOUT LEADS:

Bioscience
Corie Ralston
Petrus Zwart
Paul Adams

Environmental Chemistry
Benjamin Gilbert
Peter Nico
Pupa Gilbert

Soft Matter
Alexander Hexemer
Thomas Russell
Yi Liu

Chemistry & Catalysis
Hendrik Bluhm
Jinghua Guo

Quantum Materials
Eli Rotenberg
Alexander Weber-Bargioni

Spin Materials
Elke Arenholz
Andreas Scholl

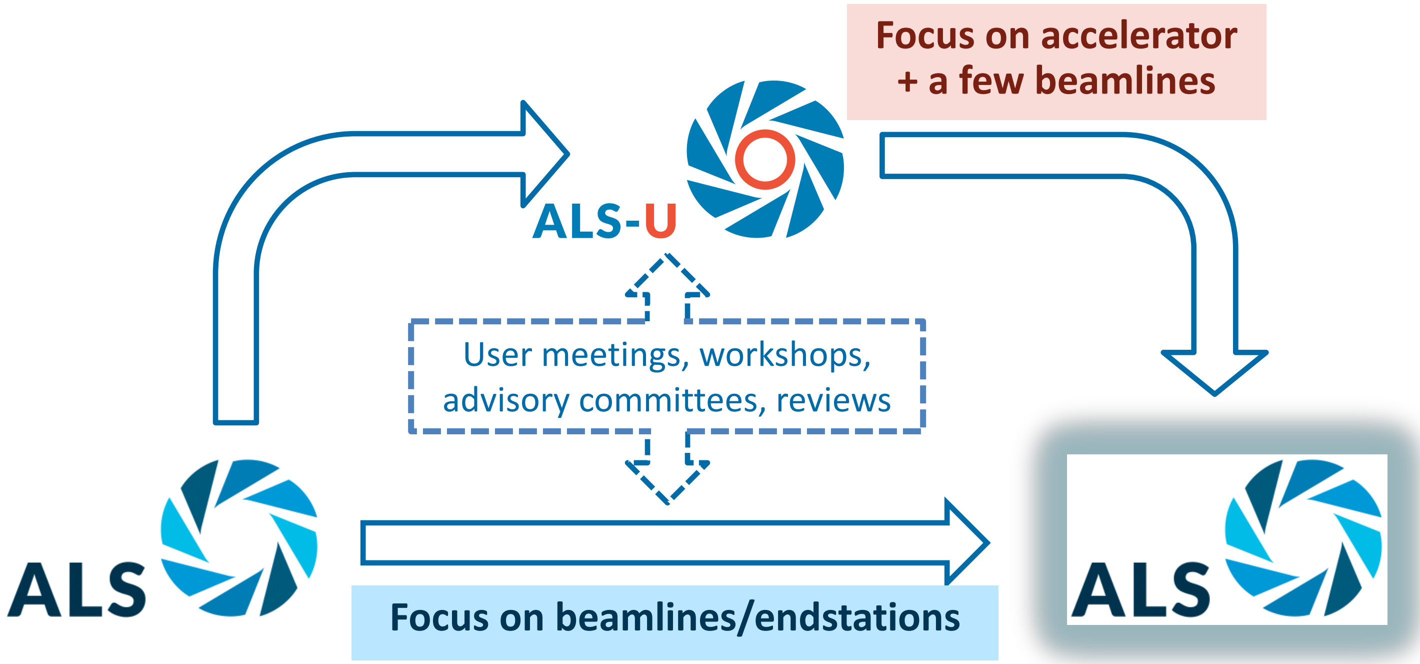
Energy Materials
Jinghua Guo

SPECIAL ASSISTANCE:
Science Writer: Ashley White
Administrative: Mayra Rivas
Graphic Design: Zosia Rostomian

Full electronic version available at: https://als.lbl.gov/als-u/resources

BERKELEY LAB U.S. DEPARTMENT OF ENERGY Office of Science ALS-U

The path(s) to ALS renewal



- The ALS-U Project is independent of ALS
- Throughout the project and beyond, the ALS will continue to innovate with new and upgraded experimental systems, many of which will benefit from characteristics provided by ALS-U.
- The input and advice we receive throughout the ALS-U Project will help inform ALS strategic planning and future projects.

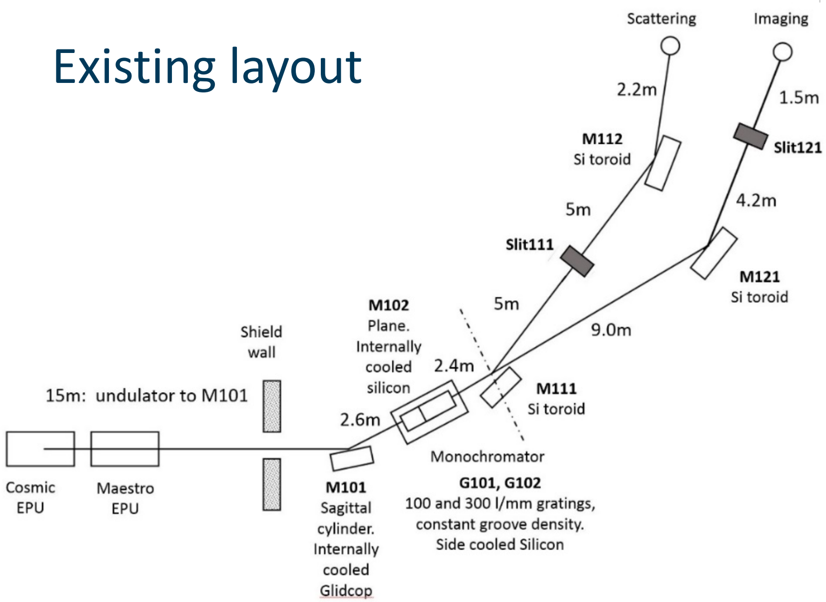
COSMIC beamline upgrade

David Shapiro
Advanced Light Source

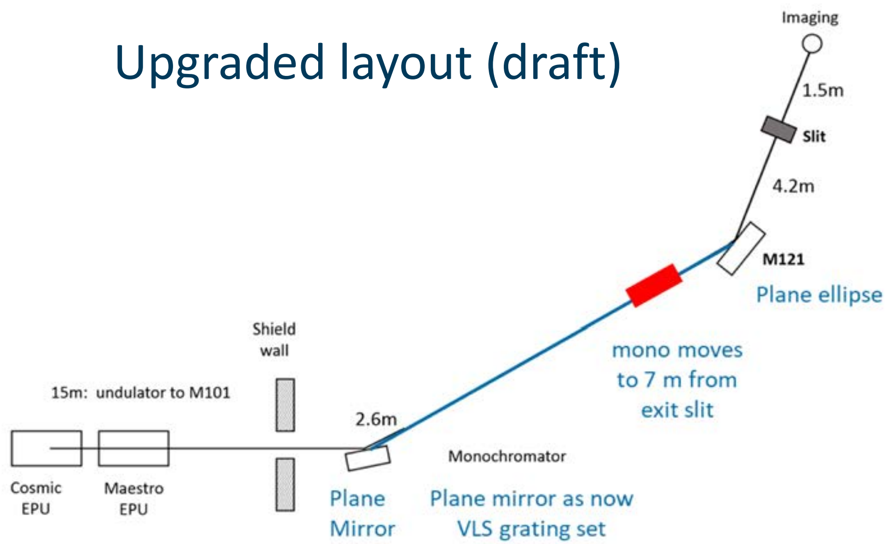
Will Chueh
Stanford University

COSMIC upgrade

Existing layout



Upgraded layout (draft)



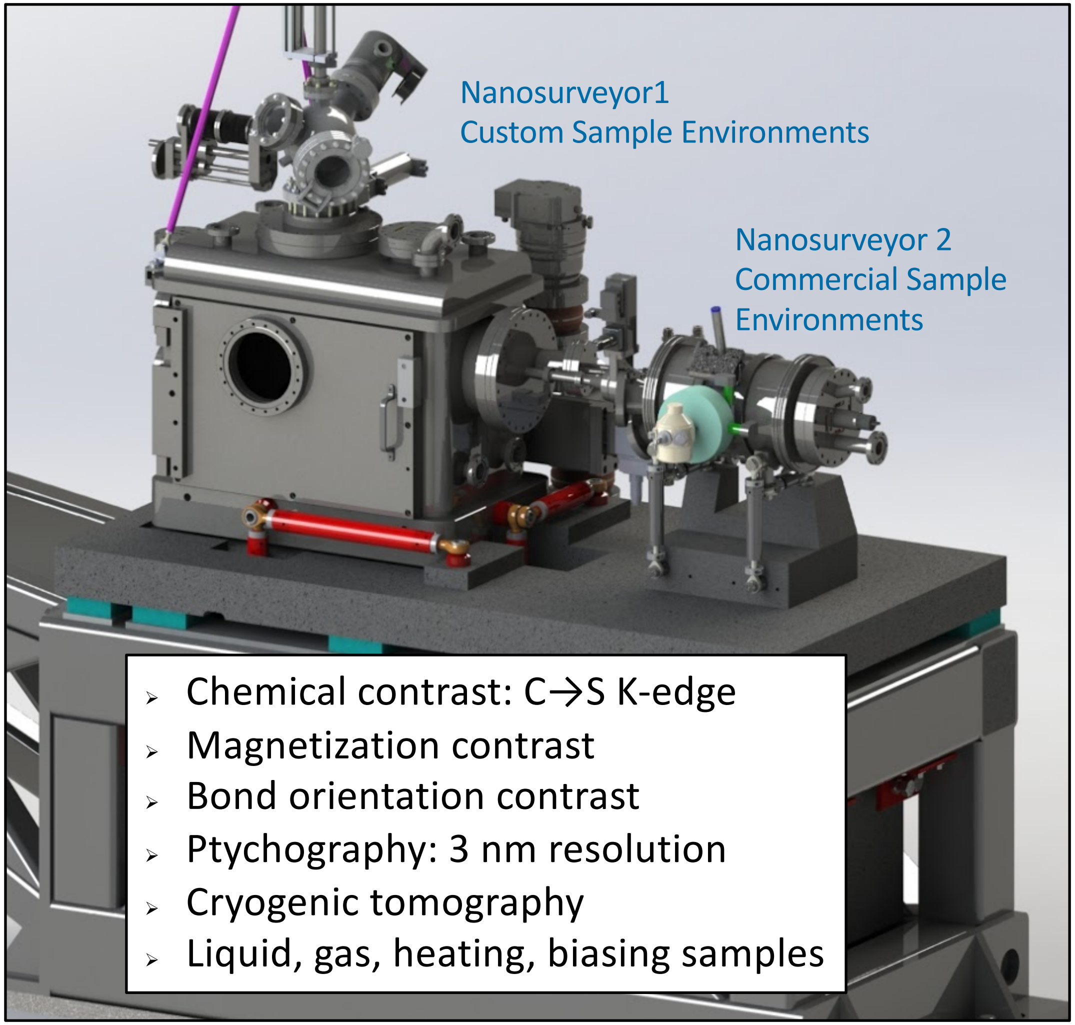
Current properties

- Separate XPCS / STXM branches
- 250–2500 eV
- Resolving power: 3,000

Upgrade scope

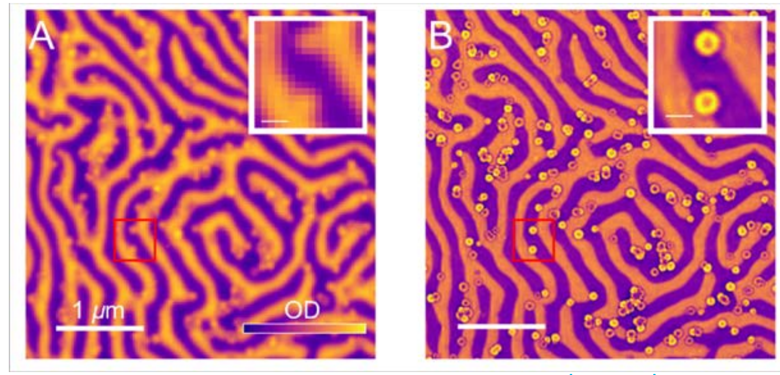
- XPCS branch relocated to FLEXON
- Two STXMs share single branch
- Optical layout re-optimized

COSMIC: Spectro-Microscopy and Tomography of Functional Nano-Materials



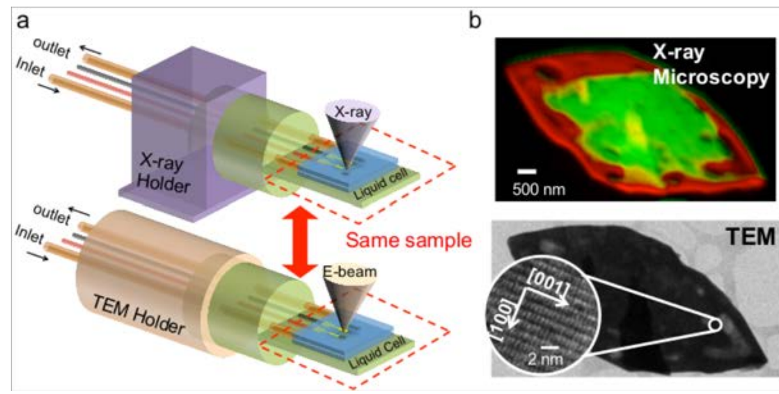
- Chemical contrast: C→S K-edge
- Magnetization contrast
- Bond orientation contrast
- Ptychography: 3 nm resolution
- Cryogenic tomography
- Liquid, gas, heating, biasing samples

Nanoscale Magnetic Structures and Dynamics



STXM | Ptychography

Operando and Correlative Imaging of Materials



COSMIC-U

- Diffraction limited beamline optics, 15X higher coherent flux
- Single-nm spatial resolution, few microsecond time resolution

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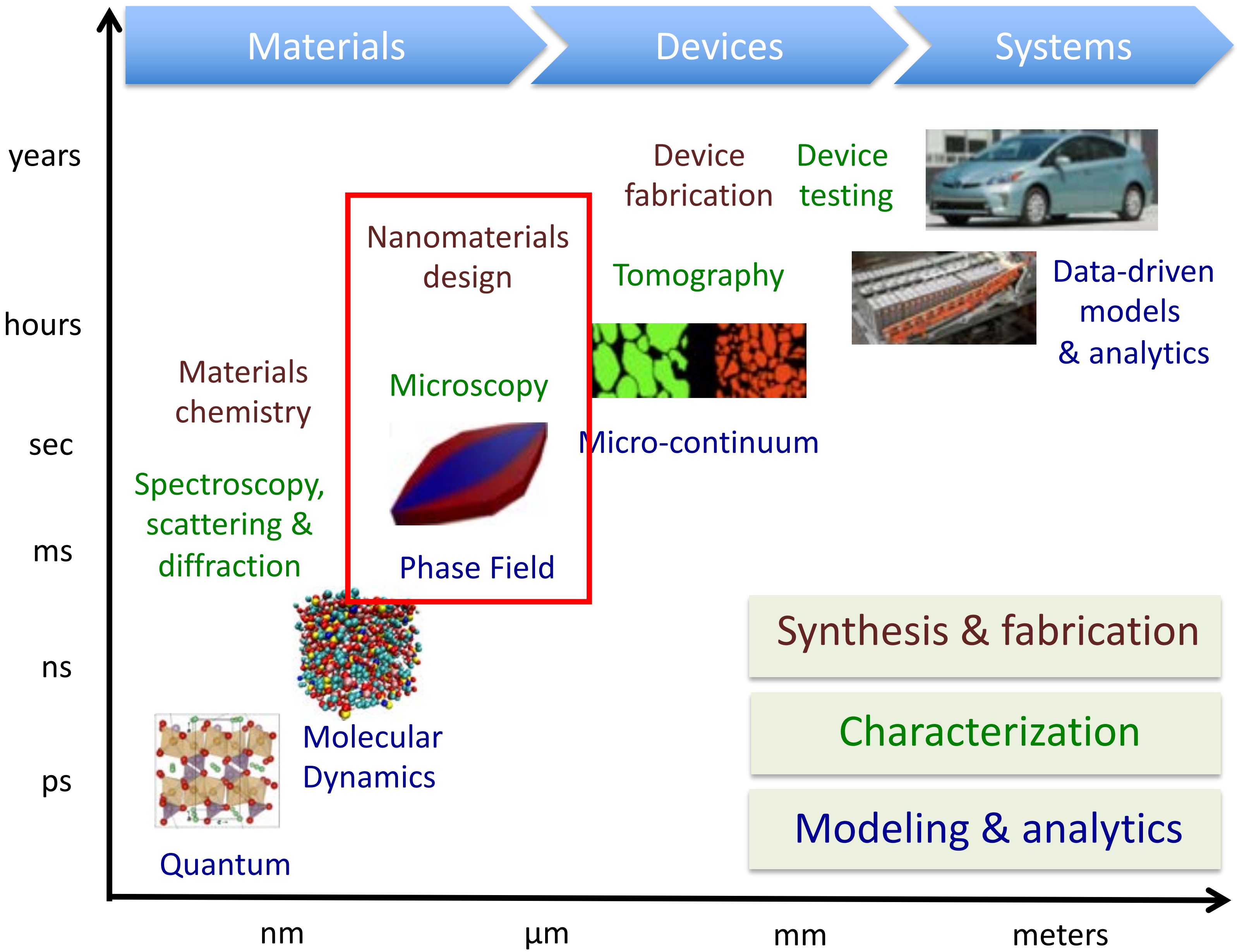
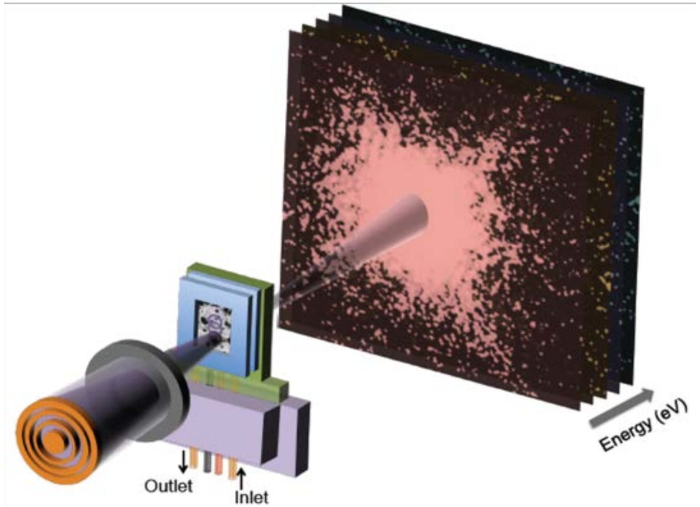
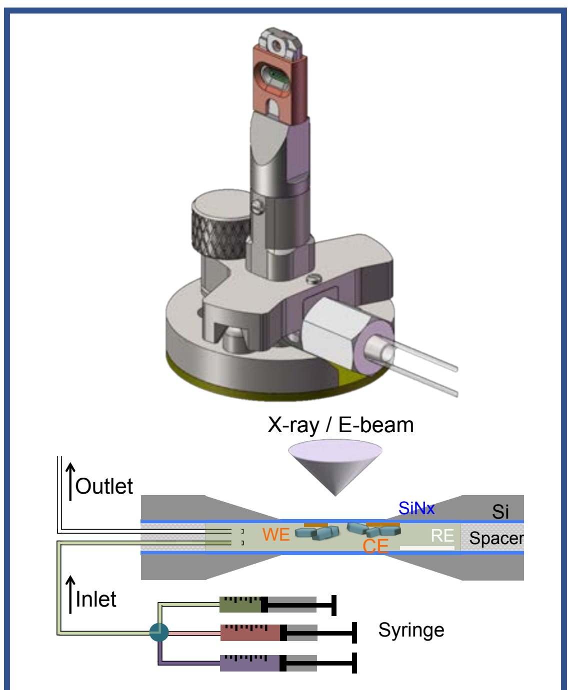
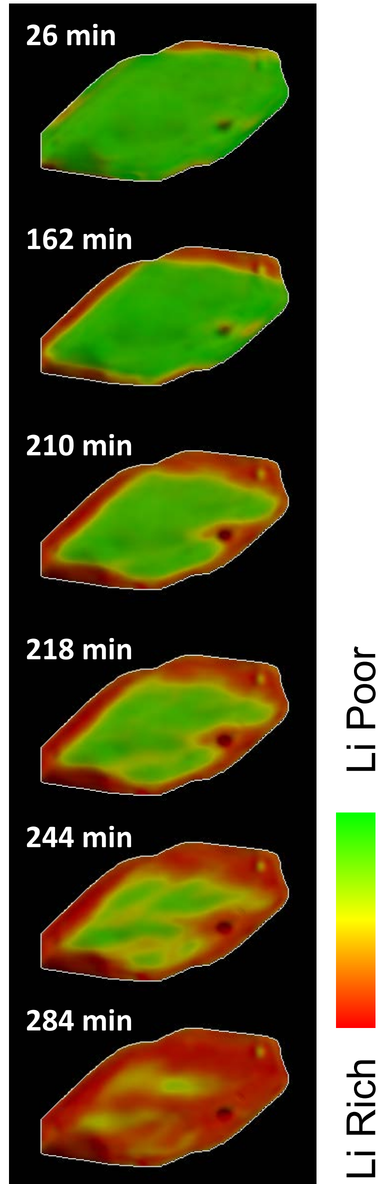
Addressing "Meso-time" Gap for Energy Materials



In-situ spectro-ptychography for investigating redox







Opportunities

- Significantly enhanced spatial/temporal resolution to reach the meso-time gap
- Understand redox reactions at the nanoscale

Challenges

- Sample damage, especially in liquid
- Data processing of sequential ptychography frames

Lim, Li, Alsem, Chueh et al. *Science* (2016).

Lim, Yu, Chueh, Shapiro et al. *In preparation*.

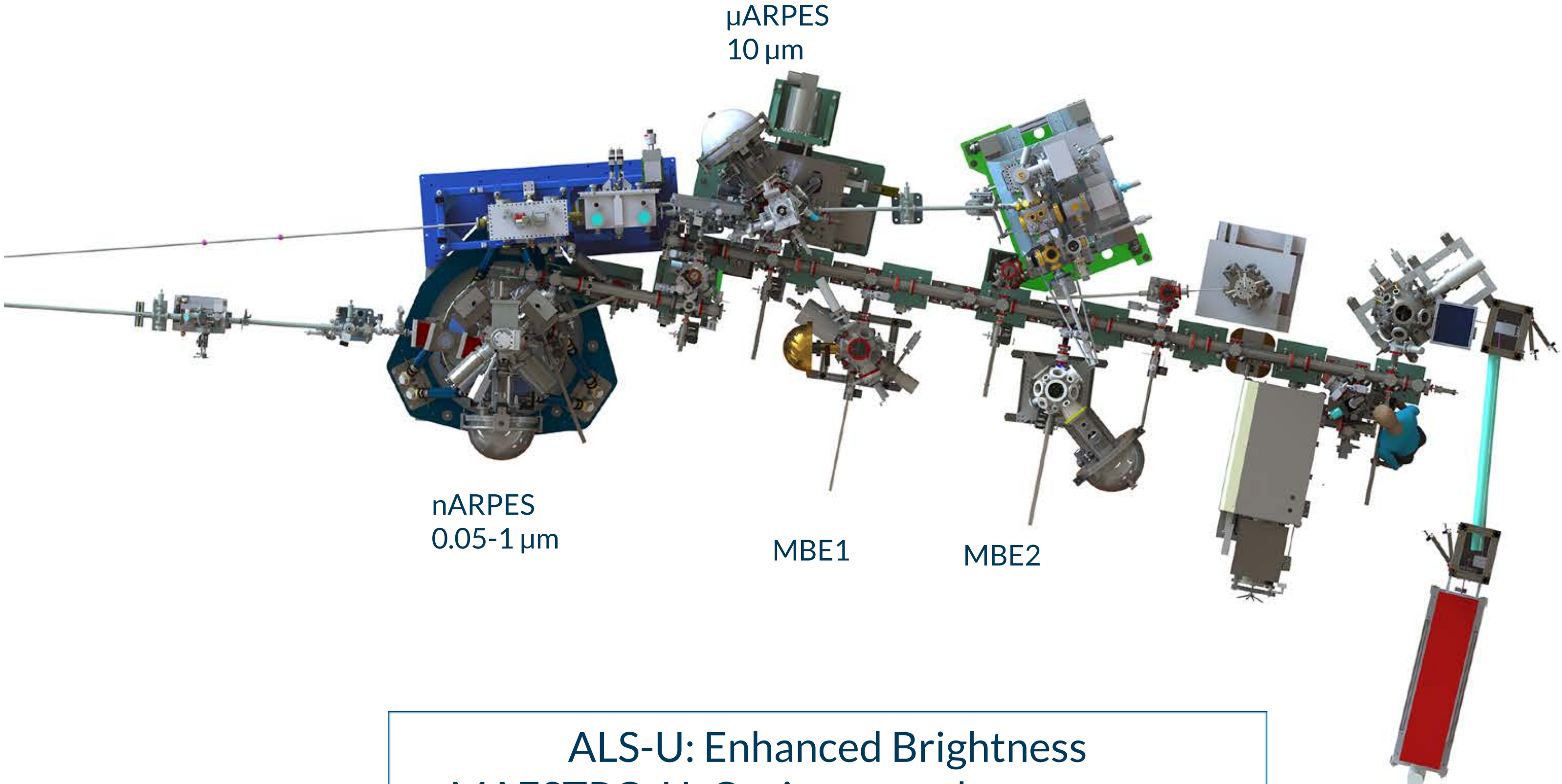
MAESTRO beamline upgrade

Eli Rotenberg
Advanced Light Source

Jyoti Katoch
Carnegie Mellon University

MAESTRO and U

https://sites.google.com/a/lbl.gov/maestro/



ALS-U: Enhanced Brightness
MAESTRO-U: Optics upgrade to preserve brightness

25–30x signal improvement over today's MAESTRO

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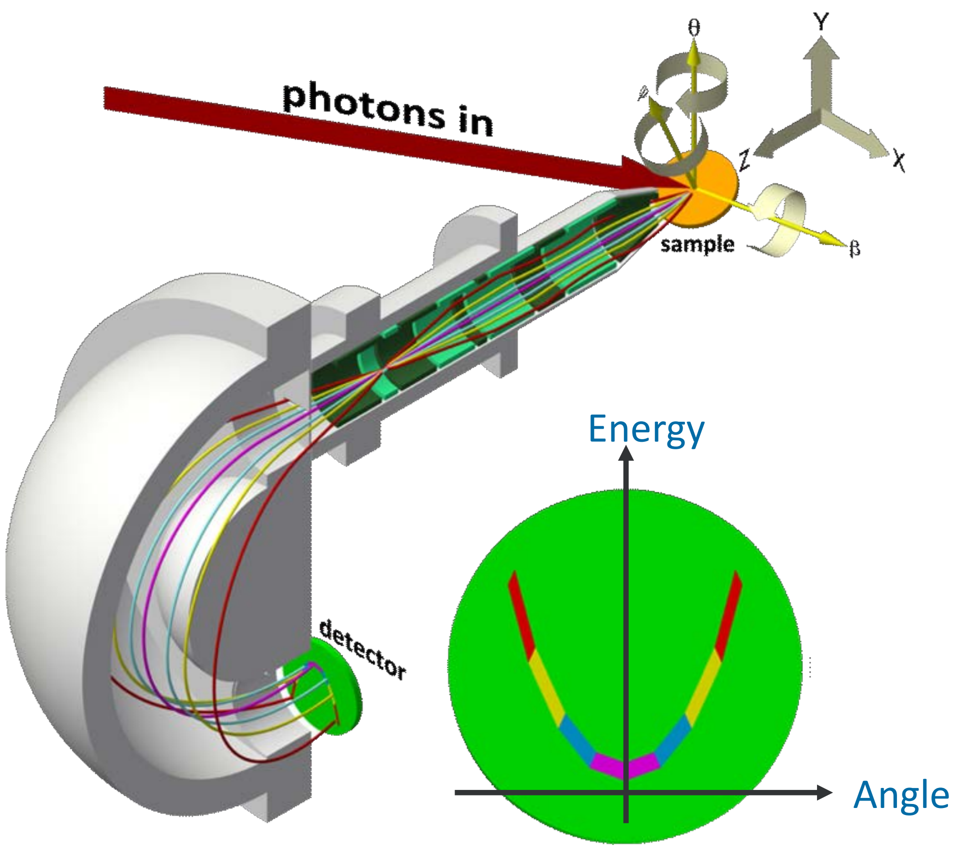
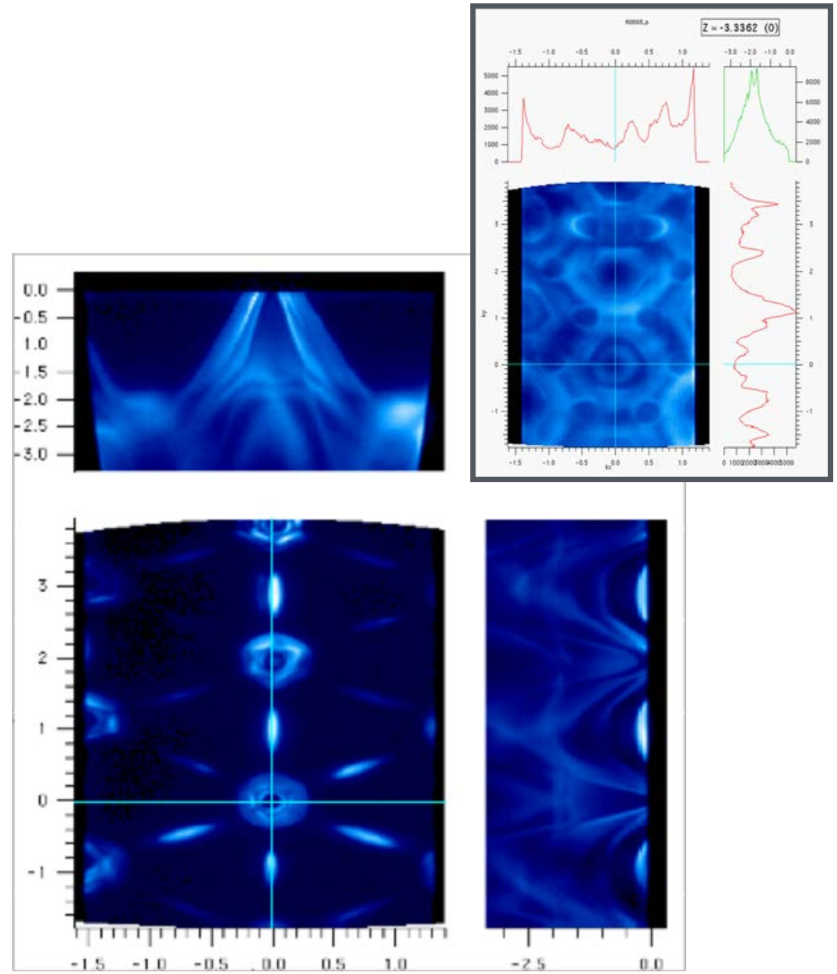
Angle-resolved photoemission spectroscopy





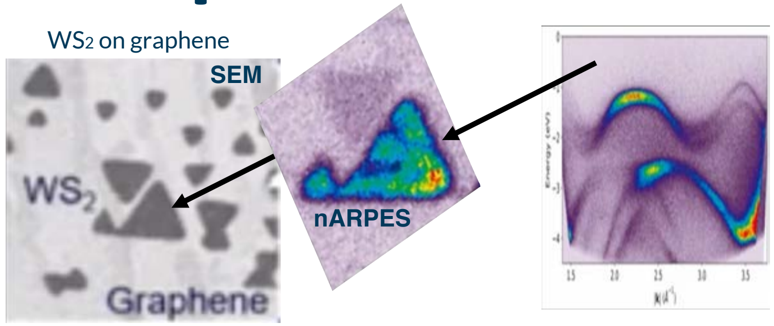
$$(\theta, \mathrm{KE}, \Phi_W) \rightarrow (\mathbf{k}, \omega)$$

The ultimate spatial resolution

too big

macroscopic dimensions
100 nm

WS2 on graphene

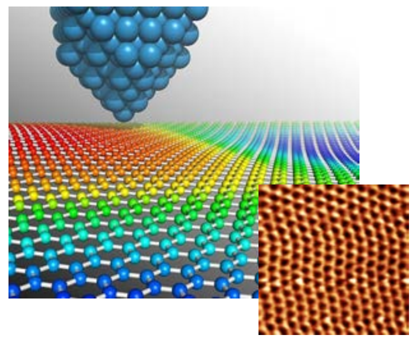


We do this now:

bulk properties of **small things**.
(ongoing 10 years of transformative, pre-ALS-U science)

too small

atomic dimensions
~ 1 nm

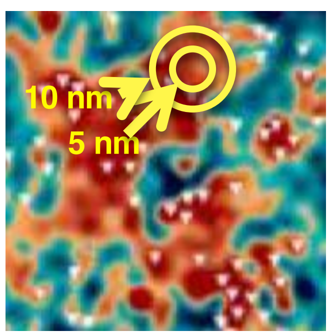


Like an STM: we would lose momentum resolution.

just right

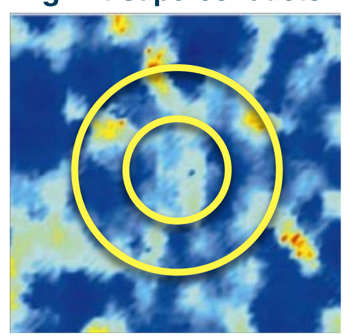
large enough for band structure, small enough to isolate quantum fluctuations and confined states
5-10 nm

(Bi,Mn)Te_3
Helical Dirac Fermions



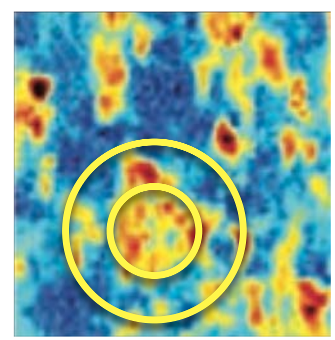
Yazdani NPhys 2011

BSCCO
High-T_c superconductor



Kapitulnik 2003

(Ga,Mn)As
Anderson Localization



Yazdani Science 2010

>> 10 years of new, transformative, ALS-U enabled science

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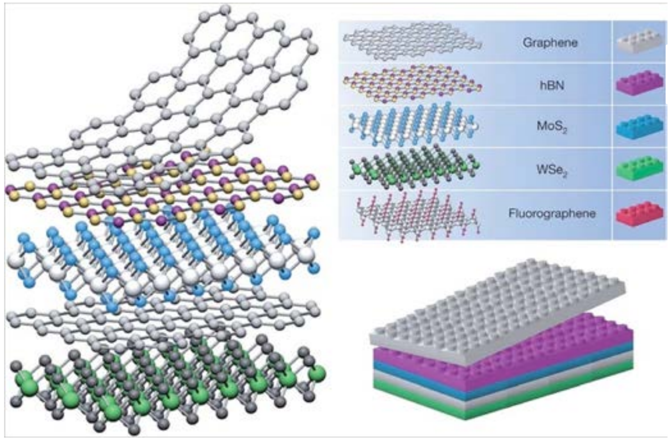
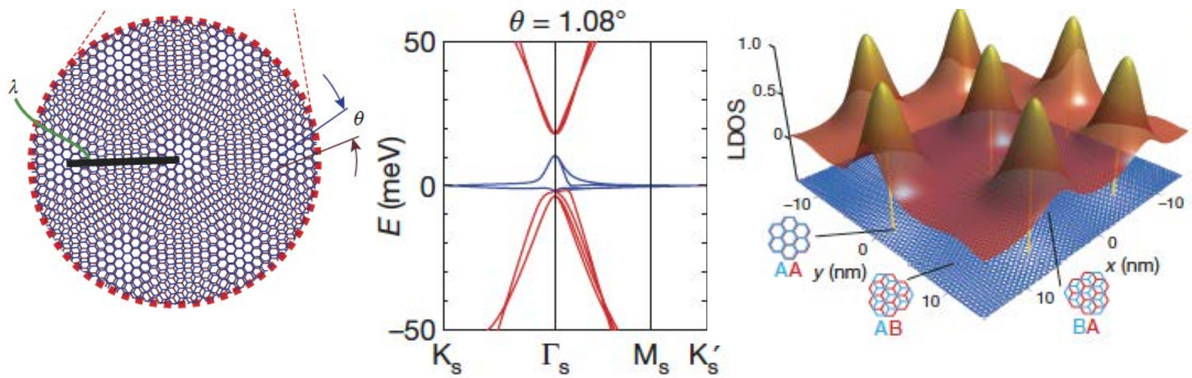
Higher spatial resolution in nanoARPES

2D based vertical/lateral heterostructures



Geim et al., Nature (2013); Sahoo et al., Nature (2018)

Twistronics

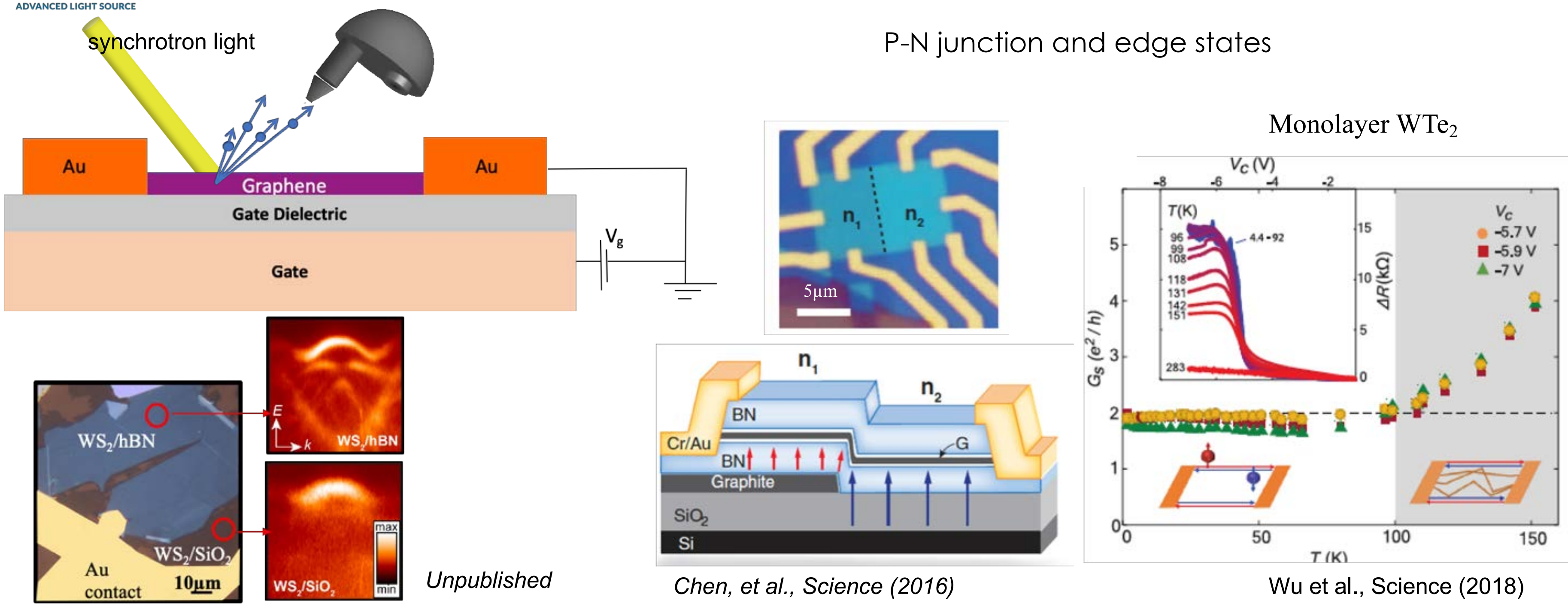


Cao et al., nature (2018)

- Higher spatial resolution nanoARPES provides opportunity to study the electronic band structure of novel 2D material with smaller grain size.
- The electronic properties of vertical/lateral 2D heterostructures are affected by immediate surrounding as well as twist angle between the constituent 2D stacking layers.
- nanoARPES with spatial resolution of 5-10 nm is a powerful technique to investigate the effects of nanoscale sized inhomogeneities in the surrounding environment that cause strong variations of electronic interactions in 2D based heterostructures.

in-operando nanoARPES

Bridging the gap between transport and ARPES measurements



Unpublished

Chen, et al., Science (2016)

Wu et al., Science (2018)

- Simultaneous transport and spatially-resolved nanoARPES measurements.
- Direct investigation of the conducting edge states, valley Hall effect, and exciton Hall effect in TMDCs.

New tender x-ray beamline

Chenhui Zhu
Advanced Light Source

Pupa Gilbert
Univ. of Wisconsin–Madison

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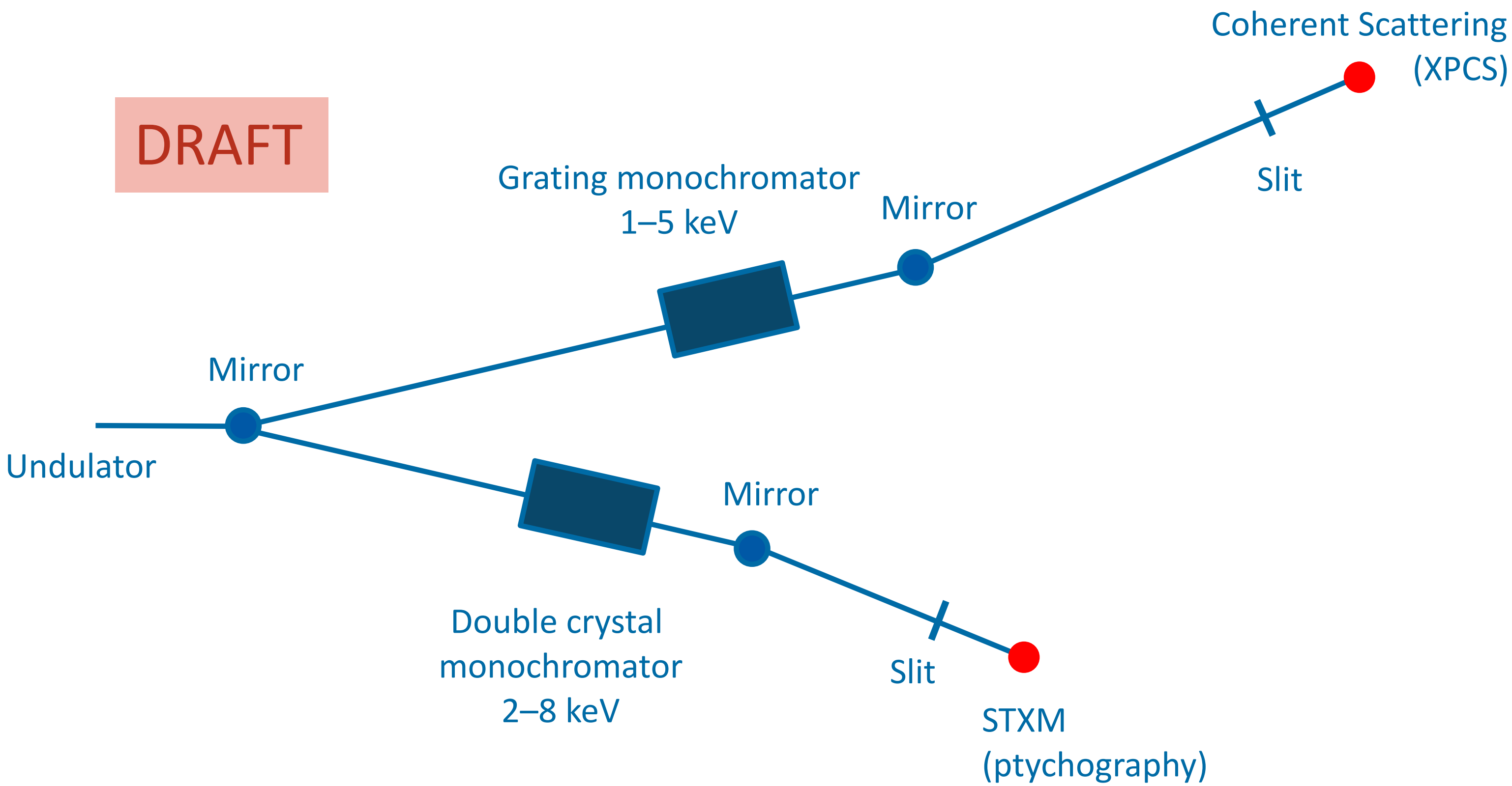
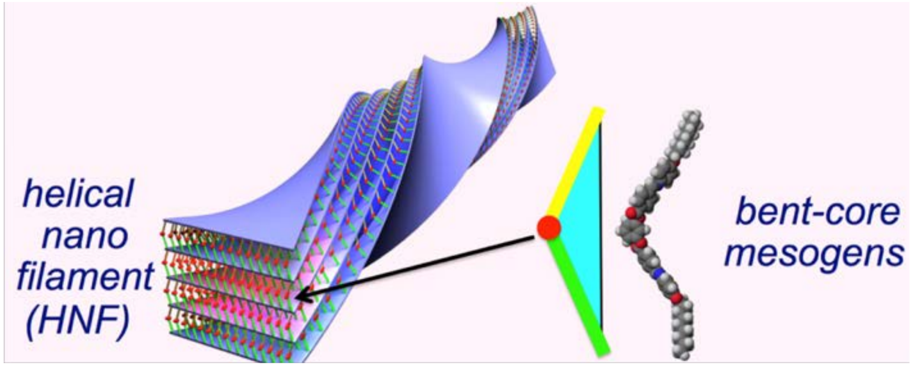
Tender beamline layout

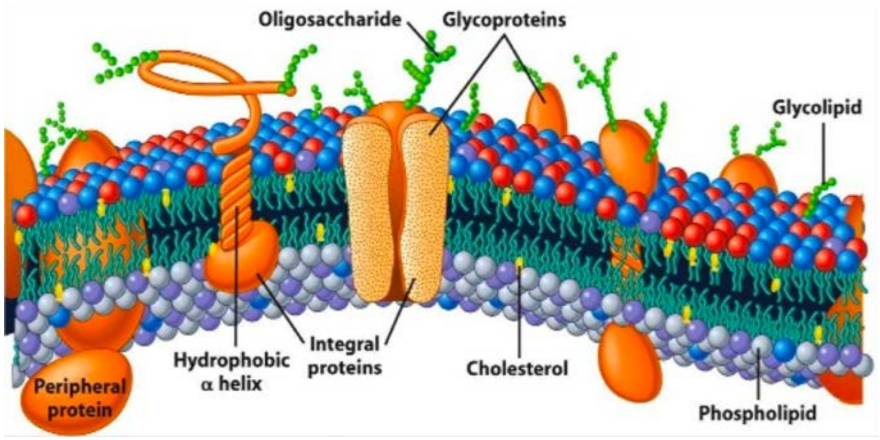


- 1–5 keV (up to 8 keV at 2nd branch), full length ID, linear polarization
- Branchline 1: grating mono (1–5 keV), ~5 micron focus
- Branchline 2: crystal mono (2–8 keV), ~100 nm focus

Tender XPCS: probe fast spontaneous fluctuations across broad length scales

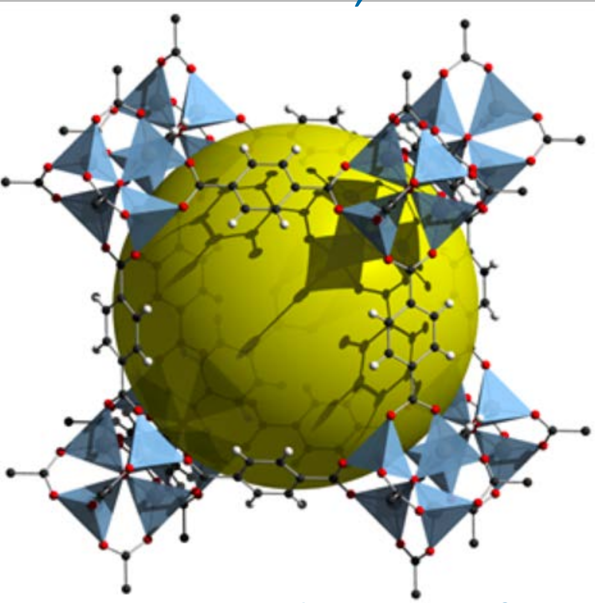


Complex fluids
Noel Clark, Colorado



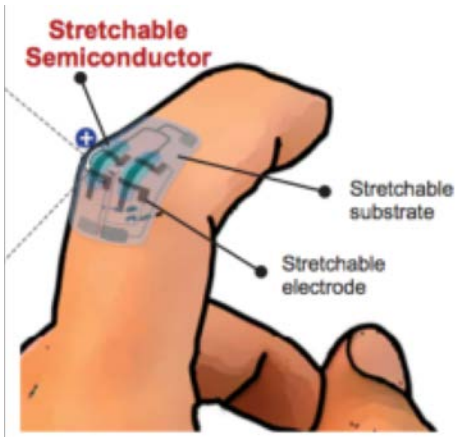
Cell membrane
Sunil Sinha, UCSD

- Physics
- Biology
- Chemistry
- Energy
- Materials science
- Nanotechnology



Metal organic framework
Omar Yaghi, Berkeley

In-situ environments:
Ambient pressure XPS,
tensile, IR, printing…



Flexible electronics
Zhenan Bao, Stanford

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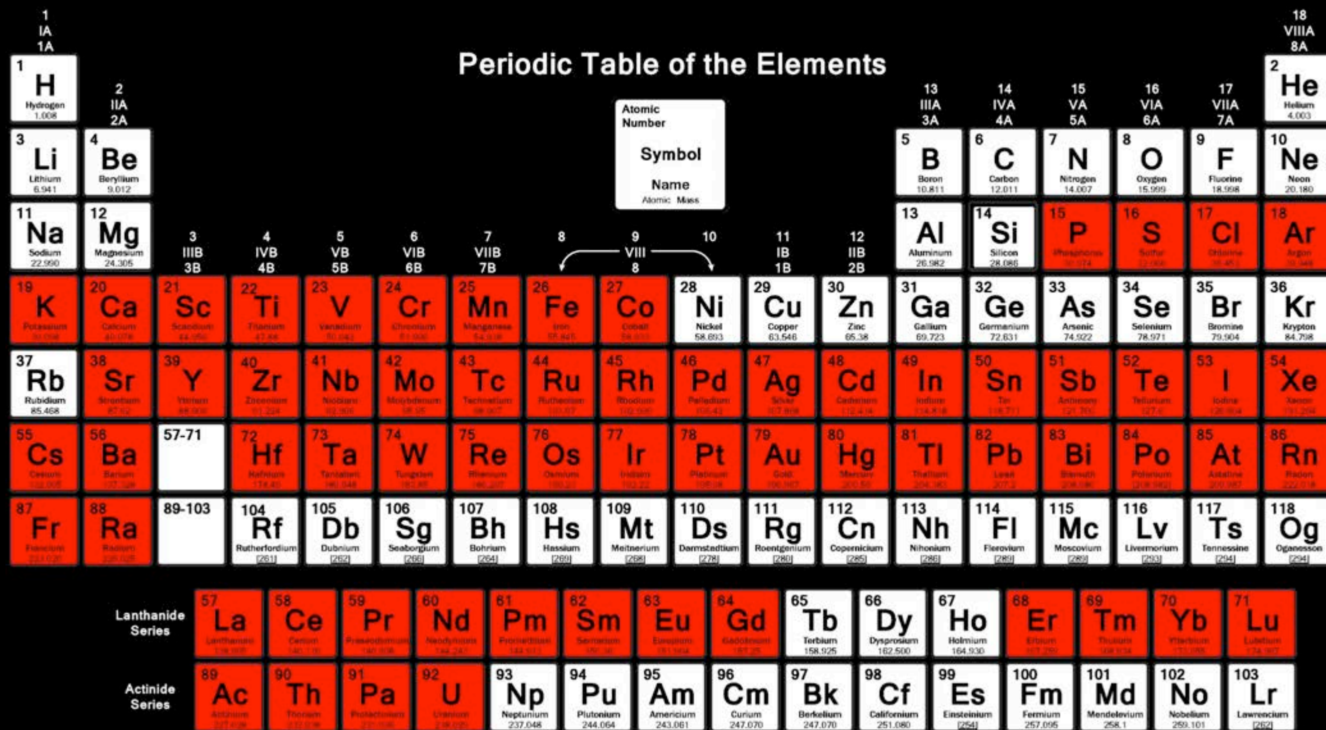
COherent **M**icroscopy of **E**arth-samples with **T**ender-x-rays (**COMET**), if funded by NSF in 2019, COMET will lead the world in tender ptychography, and will be fully operational in 2022, well before ALS-U.

Why tender-x-rays (2-8 keV)?

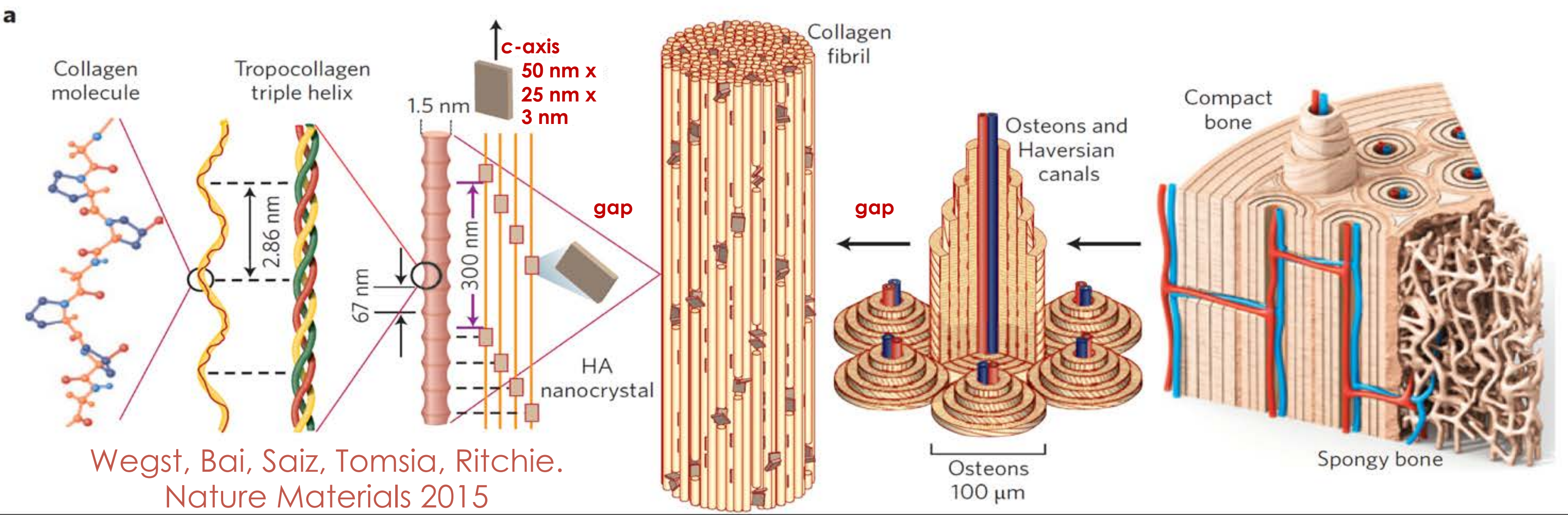
Because they can probe most of the periodic table (1s, 2p, 3d orbitals)



tender-x-rays are penetrating, thus samples can be ~1-100 µm thick, probing entire eukaryotic cells, tissues, and rocks

Pupa Gilbert, UW-Madison

we will finally access bone nanocrystals and collagen fibrils in 3D, in pristine bone



Wegst, Bai, Saiz, Tomsia, Ritchie. Nature Materials 2015

seen in their natural state, that is, interspersed nanocrystals and collagen fibrils, thus revealing the size, shape, and orientation of each nanocrystal and fibril, observing at once many nanocrystals and fibrils, their position and orientation, and how these change during mechanical stresses.
Thus revealing the functional structure of bone

Pupa Gilbert, UW-Madison

New soft x-ray beamline

Sujoy Roy
Advanced Light Source

Alex Frañó
UC San Diego

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FLEXON: A high-brightness coherent soft X-ray beamline for probing roles of multiscale heterogeneity in quantum materials

FLEXON

FLuctuation and **EX**citation of **O**rders in the **N**anoscale

XPCS | **nRIXS** | **nRSoXS**

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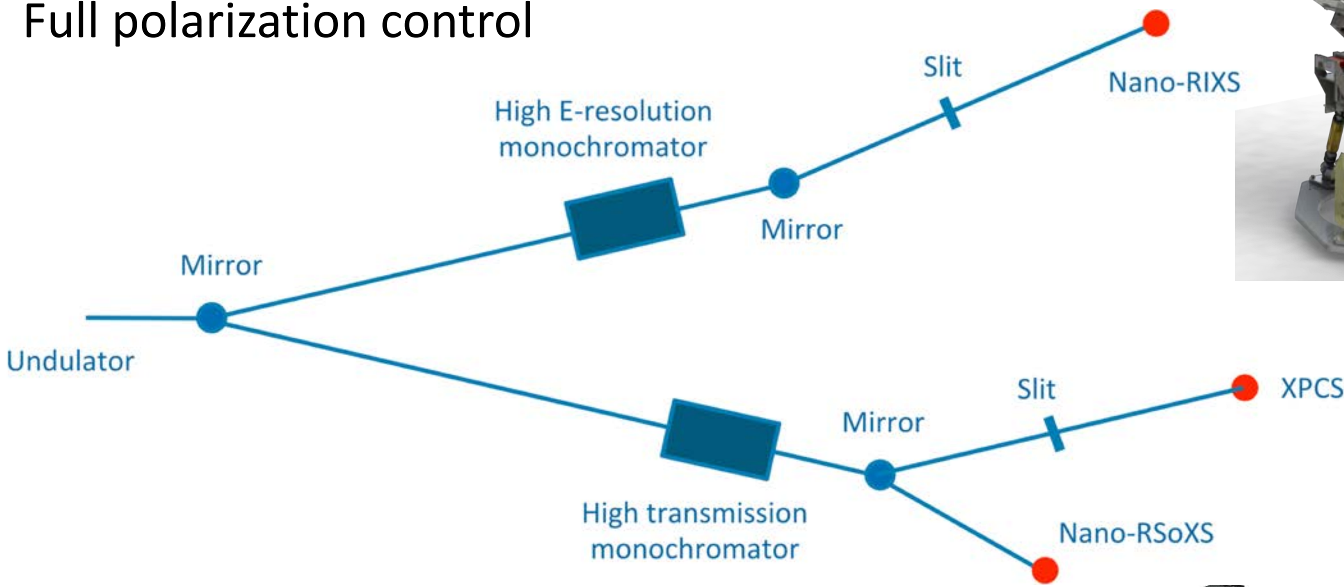
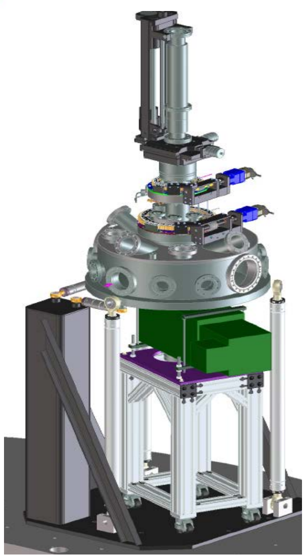
FLEXON is coming to Sector 10

Beamline Energy: 400–1400 eV
Full polarization control



nRIXS

XPCS



nRSoXS

Sample synthesis facility connected to endstations

- A unique facility with unique capabilities will lead to world-class discoveries in quantum materials.
- Evolution of nanoscale electronic and magnetic features across multiple scales in space and time.

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Phase coexistence as a form of equilibrium

Different phases in equilibrium segregate into regions → govern the macroscopic behavior

Naturally occurring

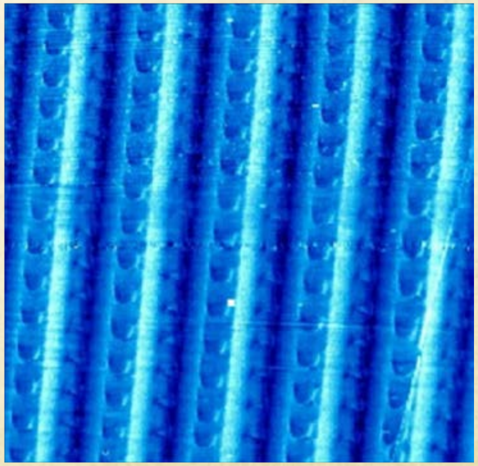
Ice+water

Magnetic (electronic) domains

Nat. Comm. **3**, 999 (2012)

Human-assisted

Domain network designed by implanted ions

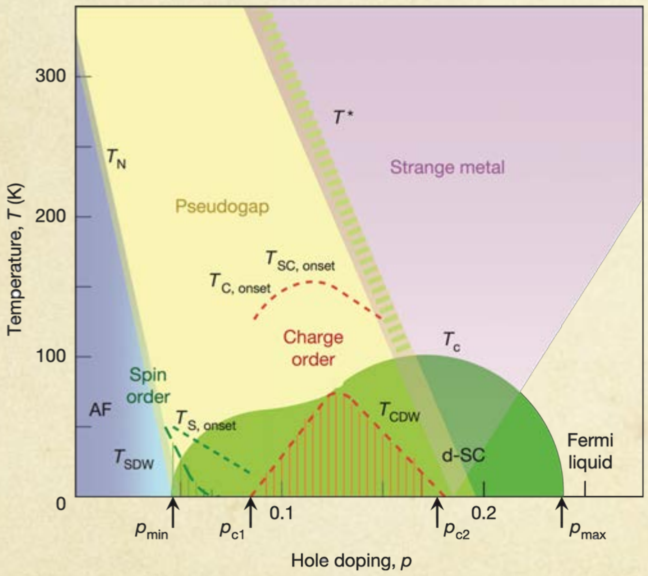


Semicond. Physics Quantum Electronics **3** (2013)

Phase coexistence at the nanoscale → FLEXON

Challenge: interplay between superconductivity and charge order?

Solution: Apply electric currents, monitor evolution upon removing superconductivity



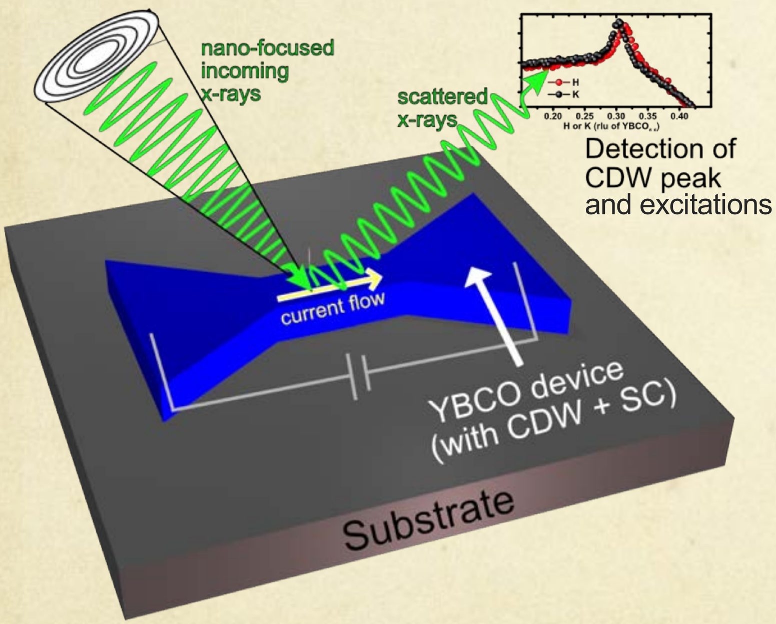
Nature **518**, 179 (2015)

High current densities (critical currents) require small nano-scale devices…nano probes!
→ need multimodal approach!

Phase coexistence at the nanoscale → FLEXON

Challenge: interplay between superconductivity and charge order?

Solution: Apply electric currents, monitor evolution upon removing superconductivity

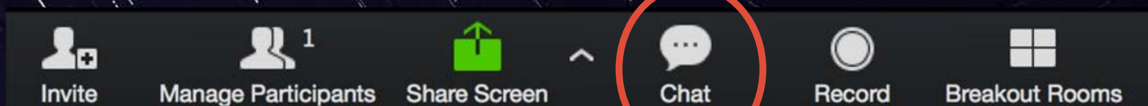


High current densities (critical currents) require small nano-scale devices…nano probes!
→ need multimodal approach!

Apply high current densities across nanodevices:

1. **<u>nRSXS :</u>** Visualize phase separation: what happens at the boundary?, etc..
2. **<u>nRIXS:</u>** Visualize excitations at the nano boundaries: plasmon and charge excitations
3. **<u>XPCS</u>:** Detect temporal fluctuations and mesoscale coherence**:** pair-density wave, nonergodic behavior compared to regions without current

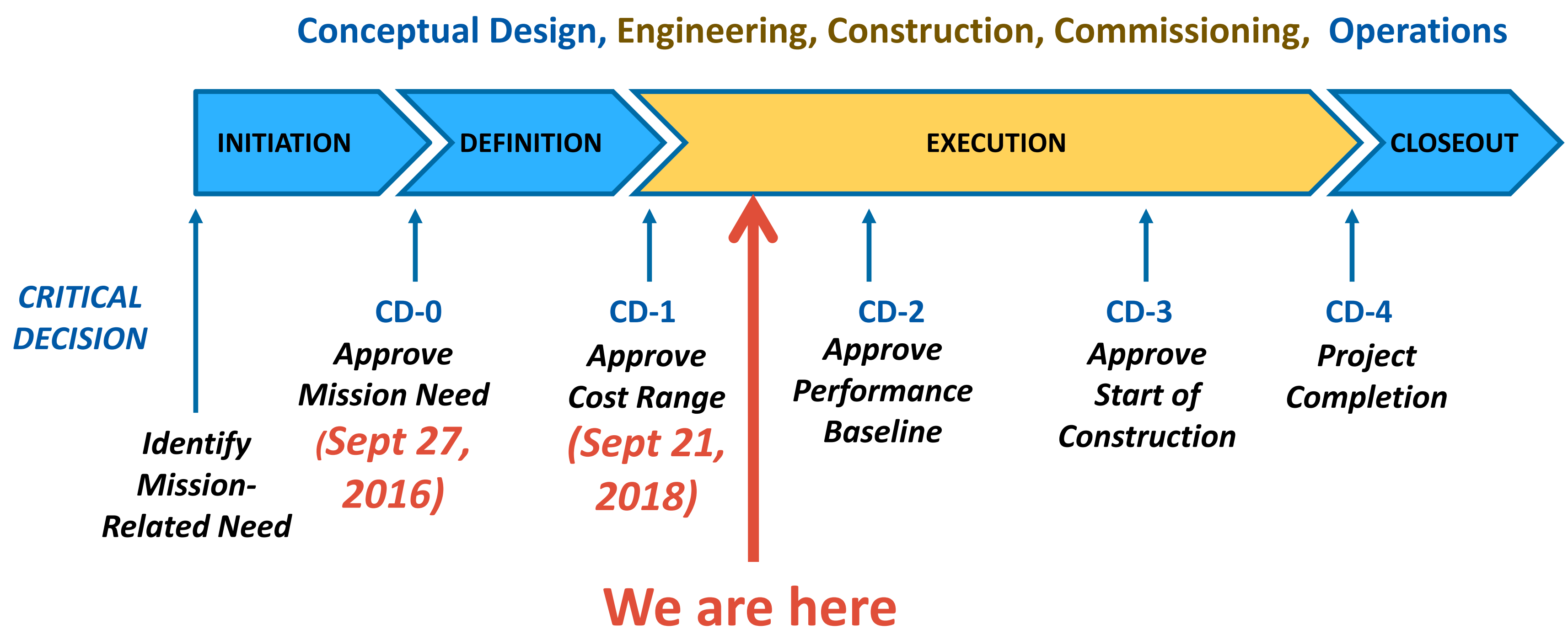
Questions



General ALS-U information: als.lbl.gov/als-u

Additional Slides

Stages of a DOE project and where ALS-U is



- Currently working on preliminary design—leads to performance baseline
  - Baseline (CD-2) is when the scope, cost, and schedule are fixed

Review committees

Steering committee (internal to LBNL):

Steve Kevan
Howard Padmore
Zahid Hussain
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