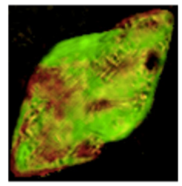
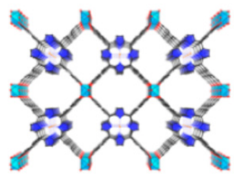
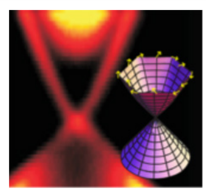
ALS-U: A Revolutionary, Coherent, Soft X-Ray Source

ALS-U
ADVANCED LIGHT SOURCE

Overview

ALS-U is a planned upgrade of the Advanced Light Source (ALS) at Berkeley Lab that will provide revolutionary x-ray capabilities. The ALS has been a global leader in soft x-ray science for more than two decades. Recent accelerator physics breakthroughs now enable the production of highly focused beams of soft x-ray light that are up to 1000 times brighter than that of the existing ALS. Applying this technology at the ALS will help us to better understand and develop the new materials and chemical systems needed to advance our energy, economic, and national security needs in the 21st century, securing the United States' world scientific leadership for decades to come.

ALS-U is designed to occupy the same facility as the current ALS but with an improved electron storage ring. The new ring will use powerful, compact magnets arranged in a dense, circular array called a multibend achromat (MBA) lattice. In combination with other improvements to the accelerator complex, the new machine will produce bright, steady beams of high-energy light to probe matter with unprecedented detail.

TRANSFORMATIVE OPPORTUNITY	EXAMPLE APPLICATION	POTENTIAL SOCIETAL BENEFITS
Understanding the critical roles of heterogeneity	 Charge motion	Energy storage, carbon sequestration, low-power computing
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

Transformative science opportunities made possible by ALS-U capabilities.

Capabilities and Science Opportunities

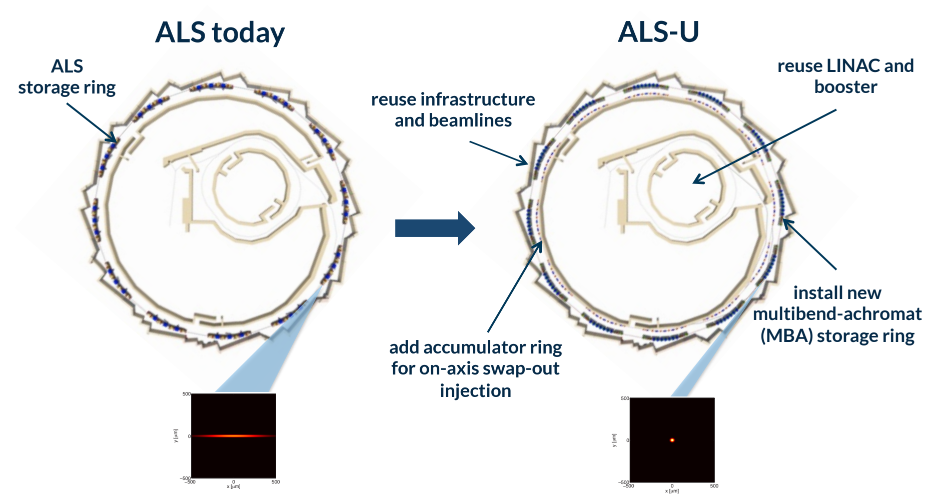
Critical advances in synchrotron-enabled science require a new generation of storage-ring-based light sources capable of providing two critical ingredients:

1. **soft x-ray light**, which has the appropriate photon energy to interact strongly with the electrons that determine the chemical, electronic, and magnetic properties of materials, and
2. **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 of materials as they function.

The improved capabilities of ALS-U will enable transformative science that cannot be performed on any existing or planned light source in the world. By combining detailed spatial characterization with the simultaneous ability to monitor a system as it functions and evolves over time, ALS-U will open doors to a broad range of exciting new science.

For example, ALS-U will enable 3D soft x-ray imaging with nanometer-scale spatial resolution and measurement of spontaneous nanoscale processes with time scales extending from minutes to nanoseconds—all with sensitivity to chemical, electronic, and magnetic properties. Moreover, the beam's high coherence through the entire soft x-ray regime will enable new spectromicroscopies to provide the groundbreaking sensitivity and precision needed to detect the faintest traces of elements and subtle electrochemical interactions on the scale of nanometers. These capabilities can be applied to a wide range of applications, including the design of energy-efficient and highly selective catalytic reactors, the creation of 3D electrochemical maps with unprecedented resolution that offer insights into improving battery and fuel cell performance, the understanding of emergent properties of quantum materials like high-temperature superconductivity, and the ability to design soft and biological materials that self-assemble and adapt to environmental changes.

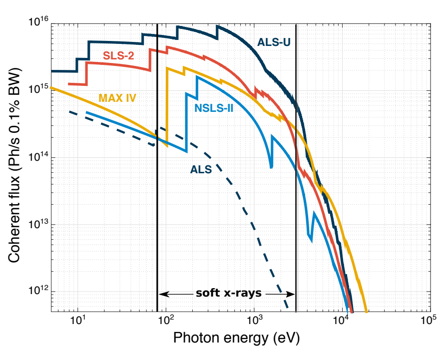
ALS-U will serve the ALS's traditional communities but also bring in new users with even broader research problems and technical requirements. In addition to providing world-leading soft x-ray capabilities, ALS-U will continue to be globally competitive in infrared and hard x-ray science and thereby will ensure a "full service" approach that combines multimodal instrumental abilities and staff expertise. ALS-U will also benefit from the many outstanding scientific research programs at Berkeley Lab and exceptional user facilities like the Molecular Foundry and National Energy Research Scientific Computing Center (NERSC).



Details of the ALS upgrade.

Approach and Scope

ALS-U will deploy an MBA lattice, first demonstrated successfully at Sweden's MAX IV facility and now planned for several new and upgraded facilities, including the Argonne's APS, which specializes in hard x-ray science. To maximize the performance of the MBA-based electron storage ring, ALS-U will employ a new, concentric accumulator ring and an electron bunch-train exchange process. Operating at a relatively low electron-beam energy of 2 GeV and a high current of 500 mA, ALS-U will produce soft x-ray beams with a coherent flux that is orders of magnitude higher than that of the ALS and well beyond the coherent soft x-ray flux of any storage-ring-based light source operating, under construction, or planned.



Coherent flux vs. photon energy of the US and international soft x-ray light sources.

The scope of work for ALS-U includes:

- Replacement of the existing triple-bend achromat storage ring with a new, high-performance storage ring based on a multibend achromat. The new ring will have the same straight-section length, location, and symmetry as the original ring, which is critical for the use of the ALS's existing beamlines.
- Addition of a low-emittance, full-energy accumulator ring in the existing storage-ring tunnel to enable on-axis, swap-out injection (an exchange of electron bunch trains between the accumulator ring and storage ring) using fast magnets.
- Upgrade of the optics on existing beamlines and realignment or relocation of the beamlines where necessary.
- Addition of three new undulator beamlines whose world-class capabilities are optimized for novel science and made possible by the beam's high transverse coherent flux.
- Upgrade of some of the utilities for better electron and photon beam stability.

We anticipate the transition from ALS to ALS-U will happen within the next decade. ALS-U will use the ALS's existing buildings, storage-ring tunnel, linear accelerator, booster, most of its 40 beamlines, shielding, and other infrastructure. By leveraging these existing valuable assets, ALS-U will provide a state-of-the-art facility for soft x-ray science at a fraction of the cost and time of a new facility with a similar number of beamlines.

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