The APS Upgrade Project

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BESAC Meeting
Bethesda North Marriott Hotel and Conference Center, Rockville MD
March 7, 2019
APS-U, a 4th generation storage ring light source, is underway

- 6 GeV, 200 mA, 1100 m circumference
- 42 pm-rad emittance
  - diffraction limit for 5.3 Å/2.3 keV
  - first hybrid 7BA lattice with reverse bends
  - on-axis swap-out injection
  - ~32 x 30 pm-rad round beam possible
- 9 superconducting and rebuilt PM planar undulators
- 100x – 1000x increase in brightness and coherence of Ångstrom and sub-Ångstrom X-rays
- 9 new high performance beamlines, 15 enhanced beamlines
- Coherence preservation in beamlines (advanced optics simulation and characterization tools)
- Stability!
- High-performance computing and AI for experiment control and data analysis
- Utilizes ~1.5 B$ of existing infrastructure
APS-U enables pivotal research across disciplines

Small-Beam Scattering & Spectroscopy
- Nanometer imaging with chemical and structural contrast; few-atom sensitivity
- Room-temperature, serial, single-pulse pink beam macromolecular crystallography

Brightness | Coherence | High Energy

Resolution with Speed
- Mapping all of the critical atoms in a cubic millimeter
- Detecting and following rare events
- Multiscale imaging: enormous fields of view with high resolution

Coherent Scattering & Imaging
- Highest possible spatial resolution: 3D visualization; imaging of defects, disordered heterogeneous materials
- XPCS to probe continuous processes from nsec onward, opening up 5 orders of magnitude in time inaccessible today,

Exploit high performance computing, artificial intelligence

Automatic control of experiments, high volume data acquisition, analysis and reconstruction
APS-U science workshops
U.S. remains a leader in high energy X-ray science with the APS-U

- **APS-Upgrade**
  - Argonne National Laboratory
  - 1,104m

- **ESRF (Upgrade)**
  - Grenoble, France
  - 844m (2020)

- **PETRA IV**
  - Hamburg, Germany
  - 2,300m (TBD)

- **HEPS**
  - Beijing, China
  - ~1360m (mid-2020)

- **SPRING-8-II**
  - Harima, Japan
  - 1,436m (mid-late 2020s)

Circumference in meters:
- Under construction: Red
- Planning Phase: Green
## APS-U new beamlines and capabilities

<table>
<thead>
<tr>
<th>Loc.</th>
<th>Name</th>
<th>Title</th>
<th>Technique</th>
<th>Key Science Example</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Wide-Angle XPCS and Time-Resolved Coherent X-Ray Scattering</td>
<td>Wide angle XPCS</td>
<td></td>
</tr>
<tr>
<td>28-ID</td>
<td>CHEX</td>
<td>Coherent High-Energy X-ray Sector for In Situ Science</td>
<td>In situ, high energy coherent scattering</td>
<td>Real-time imaging of film-growth for higher performance energy-to-light conversion, power transmission, and novel materials</td>
</tr>
<tr>
<td>33-ID</td>
<td>Ptycho</td>
<td>PtychoProbe</td>
<td>Sub-5 nm imaging with chemical contrast, extended further w/ lensless imaging to 1 nm and potentially below</td>
<td>Nano-architectured electrochemical structures &amp; Defect engineering for devices, improved materials for infrastructure, buildings, …</td>
</tr>
<tr>
<td>4-ID</td>
<td>Polar</td>
<td>Polarization modulation spectroscopy – Electronic Matter: Inhomogeneity, tunability, and discovery at extreme conditions</td>
<td>Magnetic Spectroscopy, combining nanofocusing w/ x-ray polarization, high pressure/low T/high field</td>
<td>Probe mesoscale electronic/magnetic ordering and excitations with resonant diffraction and inelastic scattering</td>
</tr>
<tr>
<td>34-ID</td>
<td>ATOMIC</td>
<td>Extremely high resolution coherent imaging of atomistic structures</td>
<td>Bragg coherent diffractive imaging, combining high spatial, temporal and strain resolutions. 3D nano-diffraction with significantly improved sensitivity</td>
<td>Image active catalytic materials approaching atomic resolution</td>
</tr>
<tr>
<td></td>
<td>3DMN</td>
<td>3D Micro &amp; Nano Diffraction</td>
<td></td>
<td>Mapping single defects in nano-crystalline materials to improve thermoelectric devices, structural integrity of mechanical components…</td>
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</table>
New beamlines and capabilities – cont.

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<tr>
<td>9-ID</td>
<td>CSSI</td>
<td>Coherent Surface Scattering Imaging for Unraveling Mesoscopic Spatial-Temporal Correlations</td>
<td>Coherent GISAXS, XPCS</td>
<td>Visualizing nano-structured metamaterials in 3D for development of novel photonic materials and improved control of light-matter interaction</td>
</tr>
<tr>
<td>20-ID</td>
<td>HEXM</td>
<td>A High-Energy X-ray Microscope</td>
<td>High energy, high resolution diffraction microscopy and high energy CDI</td>
<td>Mesoscale grain dynamics under real conditions to develop new, more durable materials</td>
</tr>
<tr>
<td>19-ID</td>
<td>ISN</td>
<td>In Situ Nanoprobe</td>
<td>In-situ trace element, chemical state and structural imaging at 20 nm spatial resolution</td>
<td>Operando studies of element dependence of transport phenomena in new energy harvesting materials, catalytic processes, …</td>
</tr>
</tbody>
</table>

Provision for future SC arbitrary polarizing emitter (SCAPE)
### APS-U Key Performance Parameters

<table>
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<tr>
<th>Key Performance Parameter</th>
<th>Thresholds (Performance Deliverable)</th>
<th>Objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storage Ring Energy</td>
<td>&gt; 5.7 GeV, with systems installed for 6 GeV operation</td>
<td>6 GeV</td>
</tr>
<tr>
<td>Beam Current</td>
<td>≥ 25 mA in top-up injection mode with systems installed for 200 mA operation</td>
<td>200 mA in top-up injection mode</td>
</tr>
<tr>
<td>Horizontal Emittance</td>
<td>&lt; 130 pm-rad at 25mA</td>
<td>≤ 42 pm-rad at 200mA</td>
</tr>
<tr>
<td>Brightness @ 20 keV(^1)</td>
<td>&gt; 1 x 10(^{20})</td>
<td>&gt; 1 x 10(^{22})</td>
</tr>
<tr>
<td>Brightness @ 60 keV(^1)</td>
<td>&gt; 1 x 10(^{19})</td>
<td>&gt; 1 x 10(^{21})</td>
</tr>
<tr>
<td>New APS-U Beamlines Transitioned to Operations</td>
<td>7</td>
<td>≥ 9</td>
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</tbody>
</table>

\(^1\) photons/sec/mm\(^2\)/mrad\(^2\)/0.1%BW

+ “Transition to Operations Parameters” for 9 new beamlines (brightness measurements)
APS-U project is on schedule

- CD-1: Approve Alternative Selection & Cost Storage
- CD-3B: Approve Long Lead Procurements
- CD-2: Approve Performance Baseline
- CD-3: Approve Start of Fabrication
- CD-4: Approve Start of Operations Project Completion

Research & Development
Conceptual Design
Preliminary Design
Design Readiness for CD-3
Procurement & Assembly
Installation & Testing

Total Project Cost = 815 M$
APS-U project is on schedule

**Funding bump in FY18 and FY19:**
- Enabled long lead procurement spending and early production of magnets, plinths, vacuum chambers, beamline components, power supplies, bunch lengthening system, etc.
- Enabled the project to really take off.

**Look ahead over next 12 months:**
- Long beamline building civil construction under way
- Magnet measurement lab complete
- 1321 storage magnets on order
- All large power supplies on order
- Plinths and supports on order
- First experimental hutch built
- Most beamline beam delivery systems and hutchès on order
- And much more
back-up
APS-U Brightness and Coherence

**Spectral brightness**

**Coherent fraction**

**Coherent spectral flux**

**Flux into 0.5 mm x 0.5 mm pinhole @ 30 m**
Hybrid 7BA lattice with longitudinal gradient, transverse gradient and reverse bend dipoles

$$\varepsilon \propto \frac{E^2}{(N_D N_S)^3}$$

- $N_D =$ # dipoles/sector
- $N_S =$ # sectors

~70-fold reduction in horizontal emittance

APS-APS-U MAC Meeting

March 12-14, 2017