Emerging Opportunities in High Energy X-ray Science: The Diffraction Limited Storage Ring Frontier

Organizing Committee:

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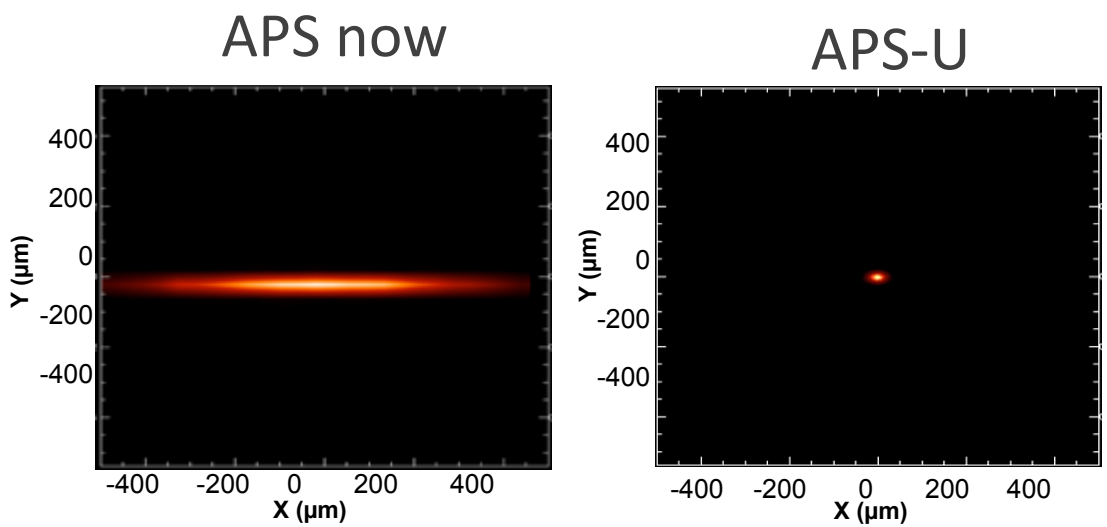
Diffraction Limited Storage Ring - Opportunity



$$\varepsilon_r(\lambda) = \sigma_r(\lambda)\sigma_r'(\lambda) \approx \lambda/2\pi$$

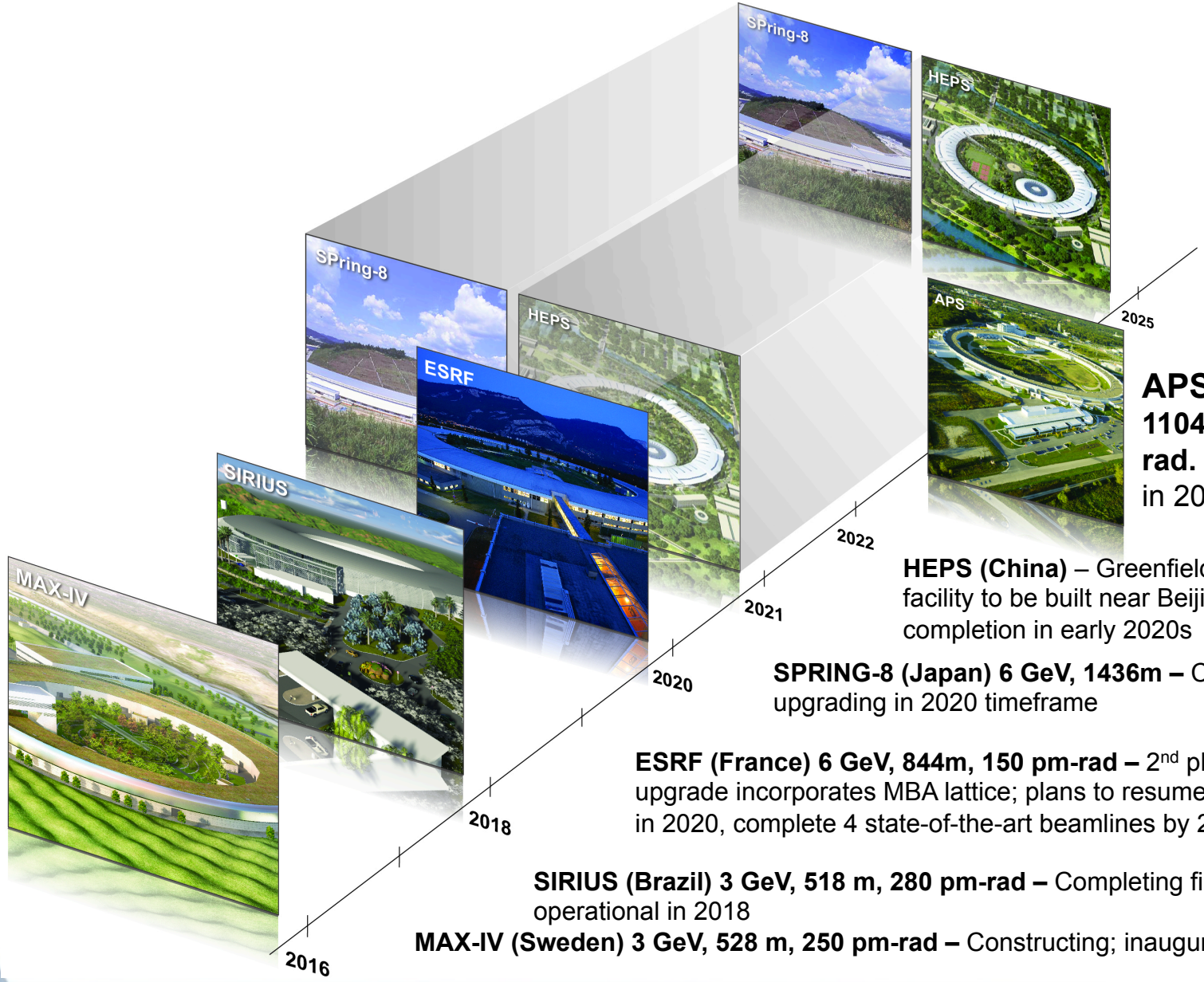
Example: 8 keV = 1.5Å $\rightarrow$ ε_r= 24 pm-rad

Present APS: $\varepsilon_x \approx$ 3100 pm-rad

$\varepsilon_y \approx$ 40 pm-rad

2-3 orders of magnitude increase in brightness, coherent flux, nanofocused flux

Worldwide march to DLSR technologies



APS-U – 6 GeV, 1104 m, 60 pm-rad. Resume ops in 2022

HEPS (China) – Greenfield accelerator facility to be built near Beijing; planned completion in early 2020s

SPRING-8 (Japan) 6 GeV, 1436m – Capable of upgrading in 2020 timeframe

ESRF (France) 6 GeV, 844m, 150 pm-rad – 2nd phase of upgrade incorporates MBA lattice; plans to resume operation in 2020, complete 4 state-of-the-art beamlines by 2022

SIRIUS (Brazil) 3 GeV, 518 m, 280 pm-rad – Completing final design; operational in 2018

MAX-IV (Sweden) 3 GeV, 528 m, 250 pm-rad – Constructing; inauguration June 2016

Adapted from July 2015 BESAC presentation

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Journal of Synchrotron Radiation

Volume 21, Part 5 (September 2014)

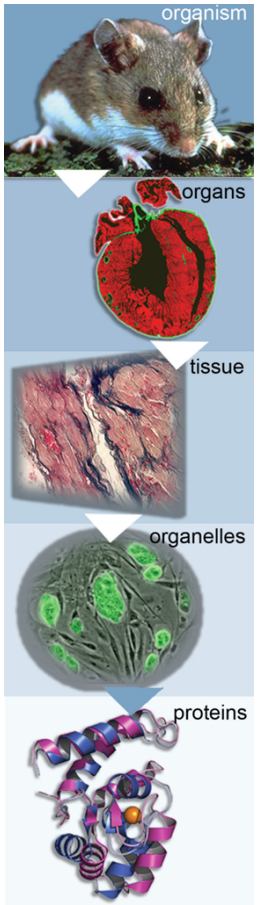
Special issue on *Diffraction-Limited Storage Rings and New Science Opportunities*

Guest Editors: Mikael Eriksson and J. Friso van der Veen

"Breakthroughs can be expected in high-resolution imaging, microscopy and spectroscopy. These techniques are relevant for many fields of science; for example, for the fundamental understanding of the properties of correlated electron materials, the development and characterization of materials for data and energy storage, environmental applications and bio-medicine."

"Higher brightness of the source will be advantageous for almost any experiment."

Workshops on Early Experiments with the Upgraded APS: May 18 - June 23, 2015



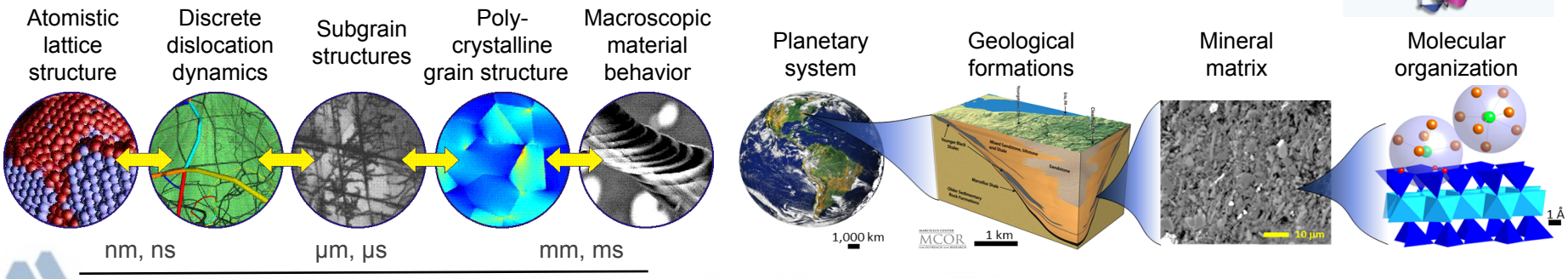
Set of six workshops covering the broad science community

- Chemistry and Catalysis
- Soft Matter
- Condensed Matter Physics
- Advanced Materials / Mesoscale Engineering
- Environmental and Geo Sciences
- Biological and Life Science

Common themes

- Imaging heterogeneity: Coherence to turn any technique into microscopy
- Probing across length and time scales: Brightness and penetrating x-ray energy to probe *in situ, operando,* including rare events
- Exploring non-equilibrium structures/processes, non-stationary phenomena
- Unraveling transport in complex systems; synthesis in action

Common challenges: Radiation damage, microfluidic sample environments, stability, detectors, data sciences



APS Upgrade Science Planning Workshops

Workshop series on Early Experiments with the Upgraded APS 2015:

- May 18-19: Chemistry and Catalysis - A. Wilkinson (Ga. Tech), David Tiede (ANL), Karena Chapman (ANL)
- May 19-20: Soft Matter - Bob Leheny (Johns Hopkins), Alec Sandy (ANL)
- May 20-21: Condensed Matter Physics - Oleg Shpyrko (UCSD), John Freeland (ANL)
- May 21-22: Advanced Materials / Mesoscale Engineering - Bob Suter (CMU), Dillon Fong (ANL), Peter Chupas (ANL)
- June 1-2: Environmental Science and Geo Science - John Parise (SBU), A. Lanzirotti (UC)
- June 22-23: Biology and Life Sciences - Gayle Woloschak (NW), Bob Fischetti (ANL)

APS-U Science Case Planning Coordinators

Paul Evans

Stephen Streiffer

Emerging Opportunities in High-Energy X-ray Science: The Diffraction Limited Storage Ring Frontier

Monday, July 13, 2015		
7:45	Refreshments	**Building 402/E1100**
	JOINT PLENARY SESSION	**Building 401/A1100**
8:15	Linda Young	Welcome
8:30	Henning Poulsen	Hard x-ray microscopy for multiscale materials science
9:00	Wendy Mao	Opportunities for high pressure science at the diffraction limit
9:30	Matt Tirrell	Multivalent interactions in ion-containing polymers
10:00	Break - Group Photo	
Chair	*David Tiede*	
10:30	Sossina Haile	Insights into Oxygen Electroreduction on (La,Sr)MnO3
11:00	Joe Hupp	AIM-ing for Catalysis (Atomic-layer-deposition In Metal-organic framework materials)
11:30	Gayle Woloschak	Biological studies with the bionanoprobe
12:00	Lunch	**Building 401/Lower Level Gallery**
		Building 401/A1100
Chair	*Stefan Vogt*	
1:45	Brian Stephenson	What can we get from improved transverse coherence at a synchrotron
2:30	Xianbo Shi	Optics considerations for APS-U

Talks in pdf to Jude Kitching – jkitching@aps.anl.gov

3:00	**PARALLEL FOCUS SESSIONS**	
	Structural Materials	**Building 401/A1100**
Chairs	*Bob Suter and Jon Almer*	
3:00	Tony Rollett	Grand Challenges in Structural Materials
3:40	Peter Voorhees	The Intersection of Simulation and Tomography
4:20	Uta Ruett	Surface diffraction with high energy X-rays
5:00	Attendees	Ideas from the floor
	Bob Suter	Thoughts from May workshop on Advanced Materials/Mesoscale Engineering
	Chemistry & Industrial Applications	**Building 402/E1100**
Chairs	*David Tiede, Pete Chupas and Mali Balasubramanian*	
3:00	Wenbin Lin	Metal-organic Frameworks for Sustainable Catalysis and Energy Production
3:40	Conal Murray	Exploring the future of nanoelectronics using x-rays
4:20	Attendees	Ideas from the floor
	Pete Chupas	Thoughts from May workshop on Advanced Materials/Mesoscale Engineering
	David Tiede	Thoughts from May workshop on Chemistry and Catalysis
	Environmental & Earth Science	**Building 402/E1200**
Chairs	*John Parise and Jesse Smith*	
3:00	Tony Lanzirotti	Opportunities in Earth, Environmental and Extreme Conditions Science at hard x-ray diffraction limited storage rings
3:40	Jennifer Jackson	Exploring atomic dynamics under extreme conditions
4:20	Attendees	Ideas from the floor
	John Parise	Thoughts from May workshop on Earth, Environmental and Extreme Conditions Science
5:30	Dinner at Argonne Guest House	(Registered dinner attendees only)

Tuesday, July 14, 2015		
8:00	Refreshments	**Building 402/E1100**
9:00	**PARALLEL FOCUS SESSIONS**	
	Materials Synthesis & Condensed Matter	**Buillding 401/A1100**
Chairs	*Paul Evans and Haidan Wen*	
9:00	Oleg Shpyrko	Coherent X-ray Nano-Vision
9:40	Darrell Schlom	Establishing How Oxide Films Grow: An Essential Part of the Materials by Design Dream
10:20	Attendees	Ideas from the floor
	John Freeland	Thoughts from May workshop on Condensed Matter Physics
	Soft Materials & Bioscience	**Building 402/E1100**
Chairs	*Byeongdu Lee and Stefan Vogt*	
9:00	Stephen Cheng	Giant Surfactants based on Precisely Functionalized POSS Nano-atoms: Tuning from Crystals to Frank-Kasper Phases and Quasicrystals
9:40	Hyunjung Kim	Use of Coherence in Hard X-rays to Study Dynamics and Structure
10:20	Attendees	Ideas from the floor
	Bob Leheny	New Opportunities in Soft Matter Research Employing High Energy X-rays
	Bob Fischetti	Thoughts from June workshop on Biology and Life Science
12:00	Lunch	**Building 401/Lower Level Gallery**
1:30	**Joint Closeout (15 min each)**	**Building 401/A1100**
Chair	*Paul Evans*	
	Structural Materials	
	Chemistry & Industrial Applications	
	Environmental & Earth Science	
	Materials Synthesis & Condensed Matter	
	Soft Materials & Bioscience	
3:00	End of Workshop	

Spare

Comparison of APS-U to other light sources worldwide in early 2020s

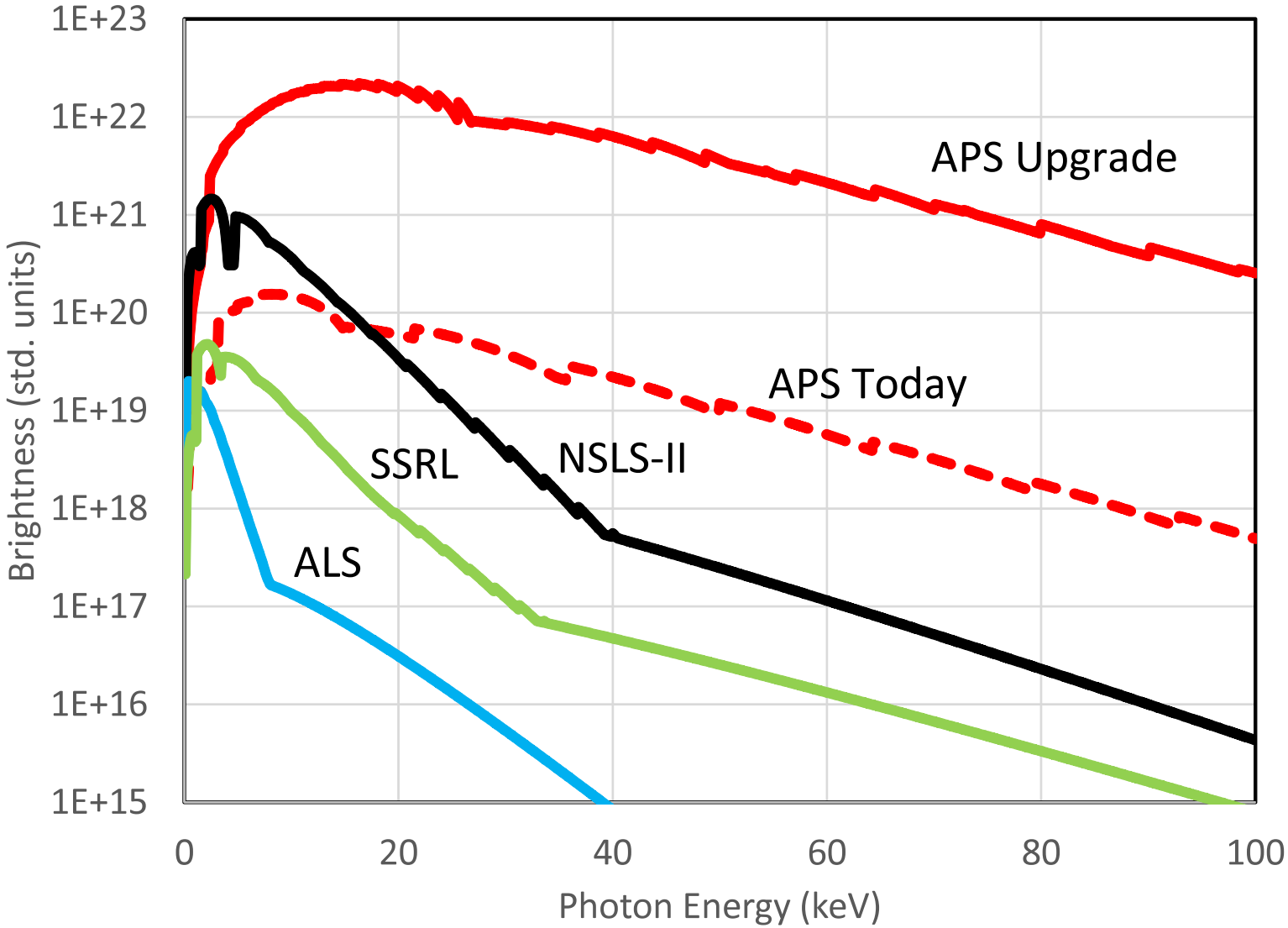
Parameter		APS Present	APS Upgrade Hi-Bright	48 Bunch	ESRF-II	SPring8-II	Petra-III	NSLS-II	MAX-IV	Sirius
Energy [GeV]		7	6	6	6	6	6	3	3	3
Current [mA]		102	200	200	200	100	100	500	500	500
Emittance, Horizontal [pm]		3113	67	48	142	99	1000	800	302	275
Brightness (*)	8 keV	1	**88**	51	61	43	4.1	3.7	13.9	22.7
	20 keV	1	**336**	144	164	137	2.9	0.8	5.2	8.1
	80 keV	1	**382**	152	154	127	1.0	0.01	0.4	0.3
Flux Density (*) (#)	8 keV	1	**4.6**	4.1	3.9	1.8	1.8	0.4	2.0	1.7
	20 keV	1	**10.4**	9.1	7.7	4.1	1.4	0.1	0.6	0.5
	80 keV	1	**10.4**	9.0	7.5	3.9	0.1	0.0	0.0	0.0
Coherent Flux	8 keV	9.3	**813**	472	562	398	38	34	129	211
(10^{11} ph/s)	20 keV	0.6	**198**	85	97	81	2	0	3	5
Single Bunch Brightness @ 8 keV (*		1	6.5	**25.5**	1.5	5.1	0.3	0.1	1.9	3.1
Flux for 10 nm focus @ 8 keV (*)		1	**88**	51	61	43	4	4	14	23

(*) Relative to present APS performance

(#) Flux Density is through a 0.5 x 0.5 mm aperture at 30 m

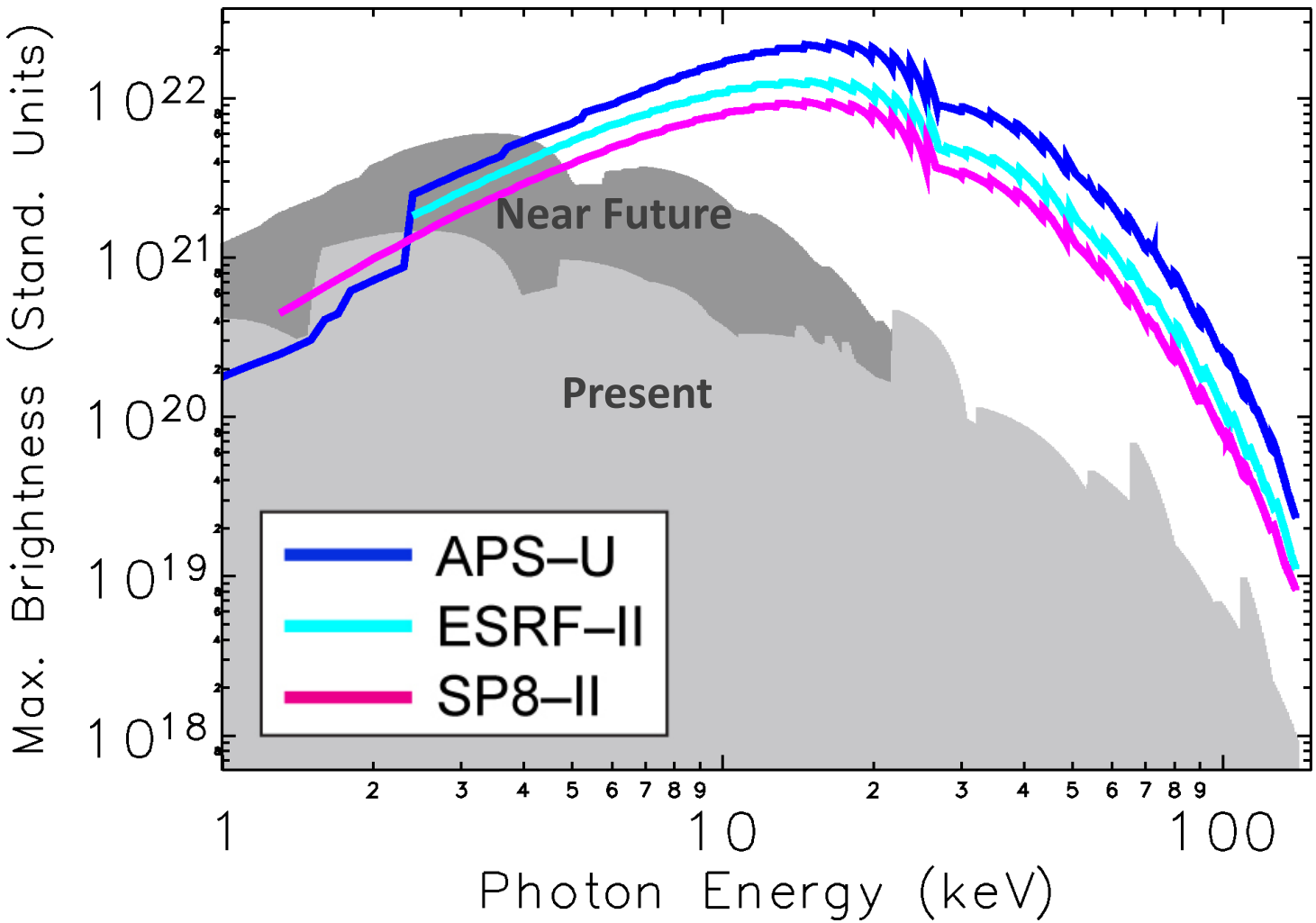
No light source now operating or under construction can match all of APS-U's technical capabilities

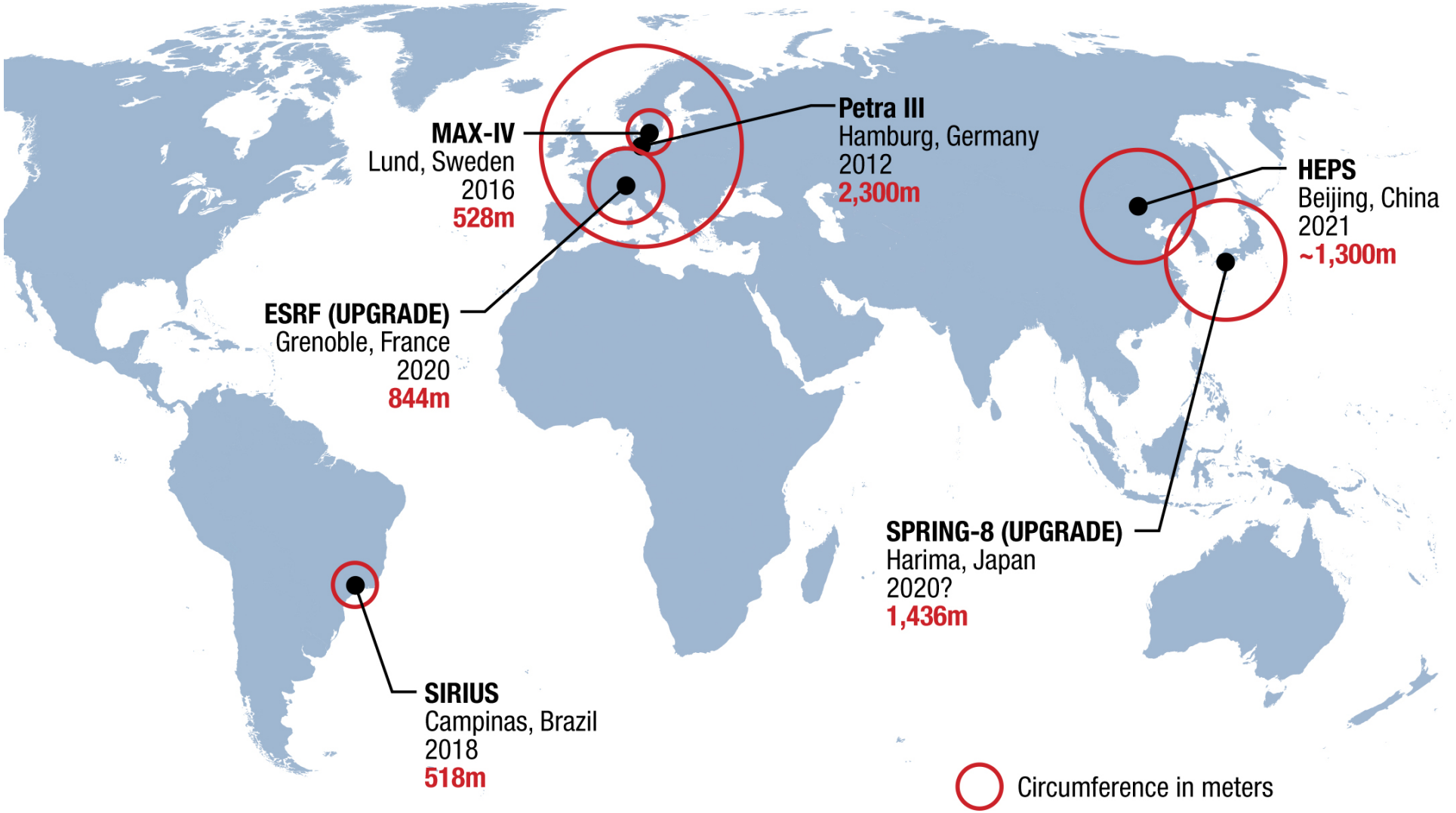
APS-U: High-energy star in U.S. X-ray facility constellation



Brightness vs. x-ray energy at top beamlines among BES synchrotron facilities

APS Upgrade ensures that the United States regains world leadership position in light sources



Curves for APS, ESRF and SP8 upgrades based on present designs, assuming identical undulators

The world's six leading storage rings in 2021 – **without APS Upgrade**