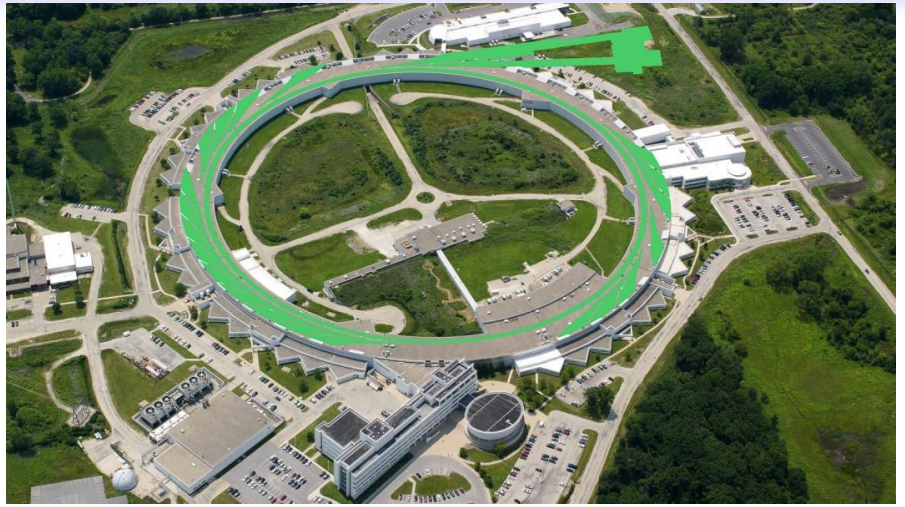
Overview of APS-U

Jesse Hopkins, PhD
IIT/CSRRI
Director, BioCAT
Sector 18, Advanced Photon Source

January 10, 2025

The APS Upgrade (APS-U)

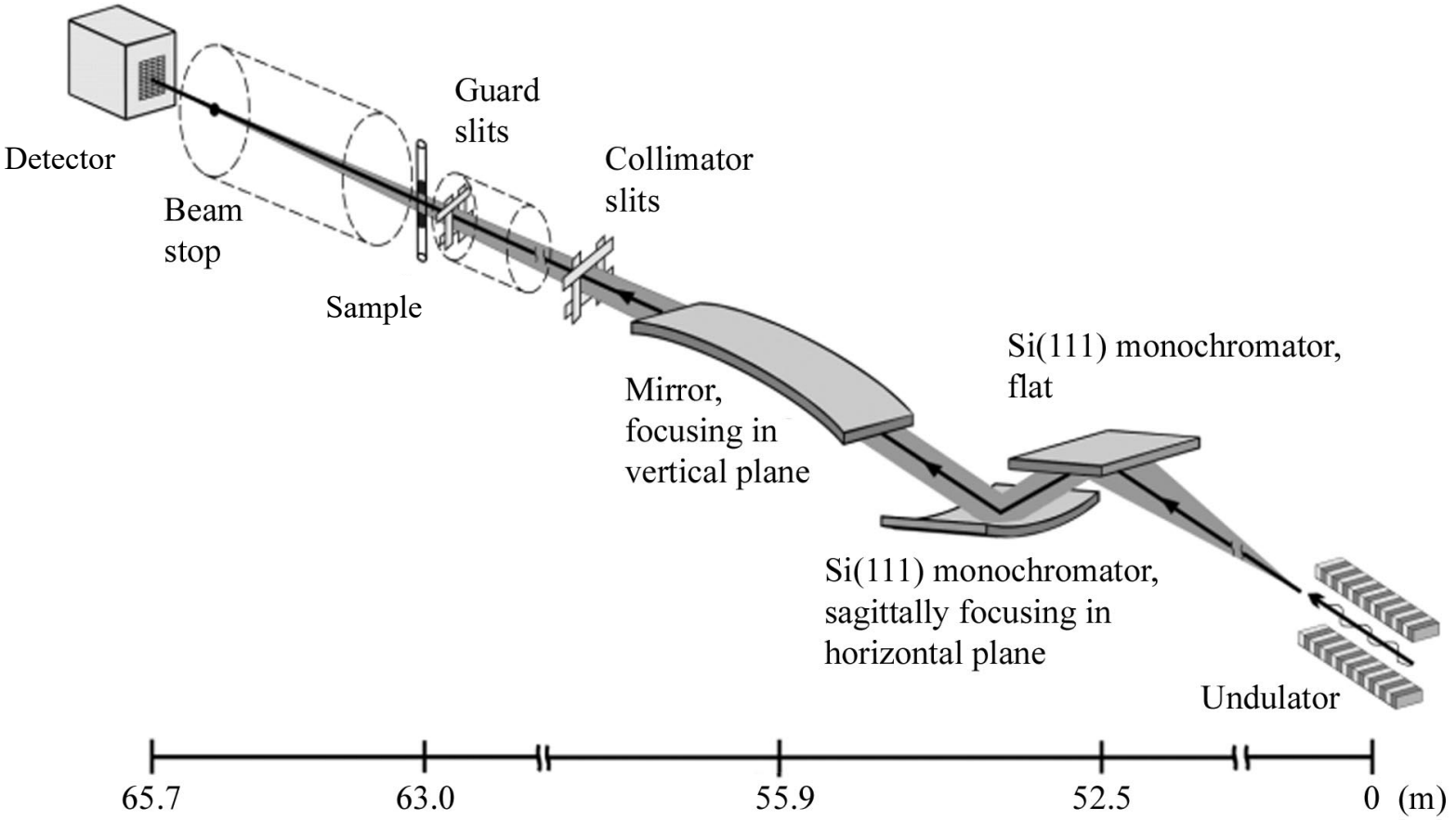
- APS upgrade is a ~18 month long upgrade project for the APS
  - Completely replace the electron storage ring
  - Improve x-ray brightness by up to 500x
- Old APS turned off April 2023
- First light at an experimental station was achieved on June 17th 2024
- BioCAT commissioning:
  - Sept./Oct. 2024: Safety validation
  - Oct./Nov. 2024: Technical commissioning
  - Dec. 2024/Feb. 2025: Scientific commissioning
- We are resuming normal user operations in mid-February 2025



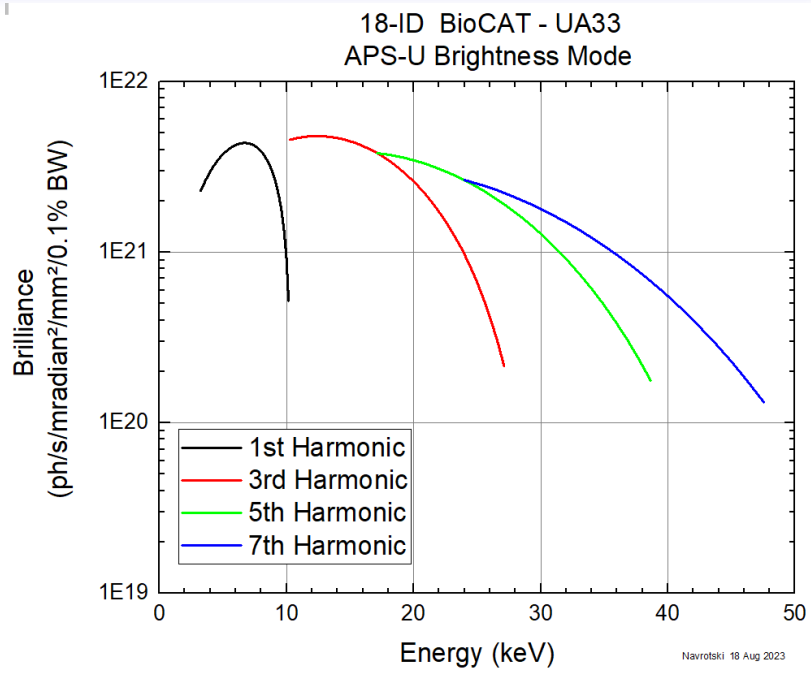
Benefits for BioCAT

- Smaller horizontal beam size
- Smaller microfocus beams
- More flux (both standard and microfocus)
- Improved beam stability and uptime
- State-of-the-art source to keep facility world class for next 25+ years

Optical performance post APS-U



Adapted from Fischetti et al. J. Synch. Rad. 11(5) 399-405 (2004).

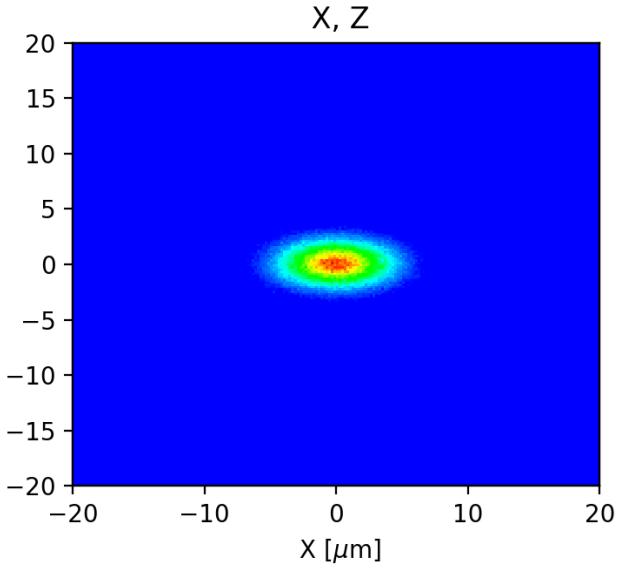


- In addition to mirror, have 2 Be CRLS for microfocus work

Optical performance post APS-U

- Simulated beam shape/flux with OASYS at 64 m at 12 keV (Yujia Ding)
- Expected flux: ~6*10^{13} ph/s @ 12 keV

Perfect upstream optics



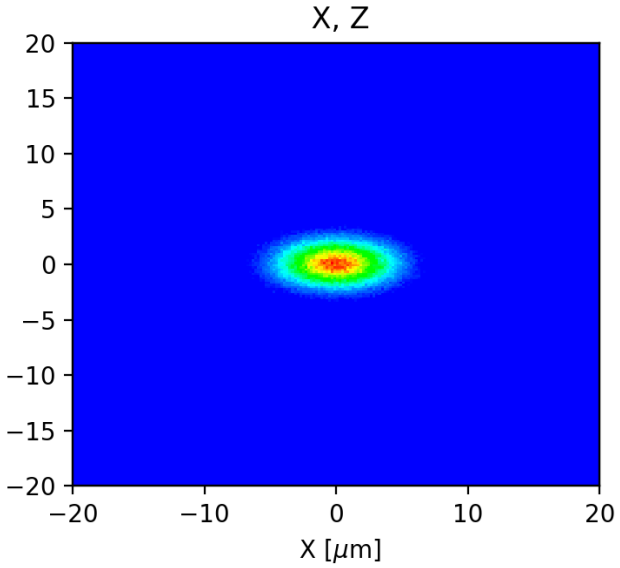
H: 5.9 μm
V: 3.0 μm

Simulations in OASYS by Yujia Ding, CSRRI/MRCAT

Optical performance post APS-U

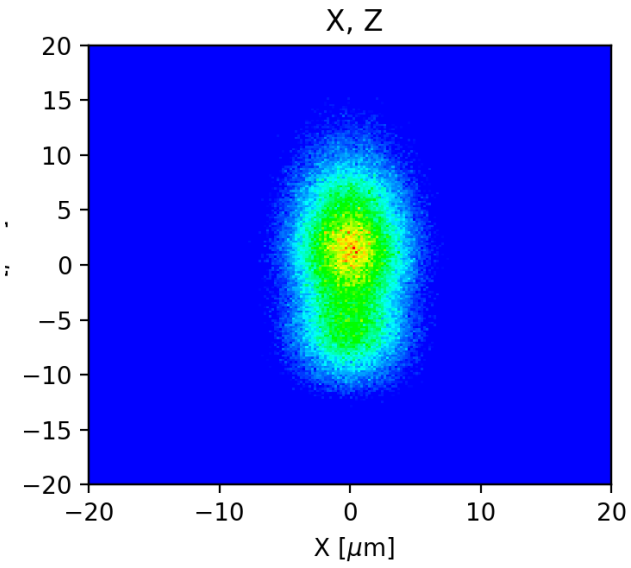
- Simulated beam shape/flux with OASYS at 64 m at 12 keV (Yujia Ding)
- Expected flux: ~6*10^{13} ph/s @ 12 keV

Perfect upstream optics



H: 5.9 μm
V: 3.0 μm

Current upstream optics



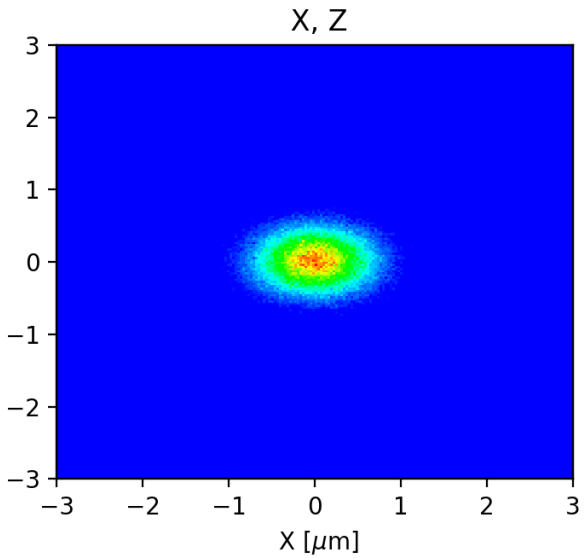
H: 5.9 μm
V: 14.3 μm

Simulations in OASYS by Yujia Ding, CSRRI/MRCAT

Optical performance post APS-U

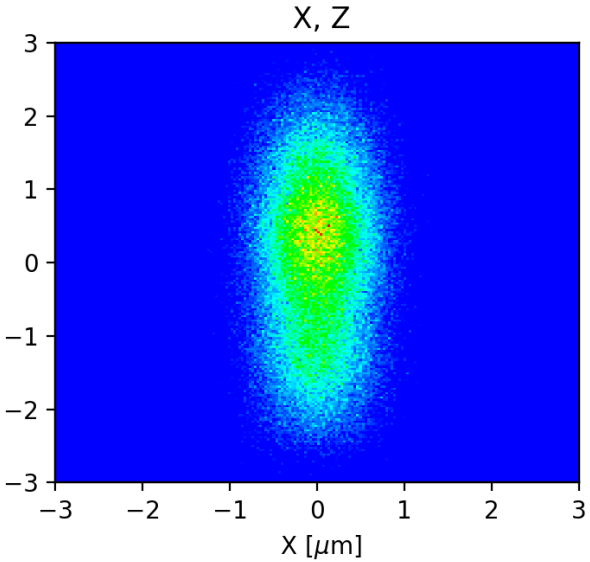
- Also simulated CRL optics
- Long focus (1.9 m) CRL
- Expected flux: ~1.6*10^{13} ph/s

Perfect upstream optics



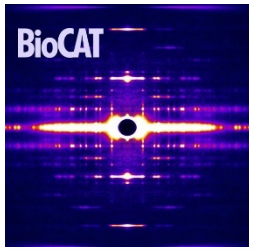
H: 0.63 μm
V: 0.92 μm

Current upstream optics



H: 0.95 μm
V: 2.90 μm

Simulations in OASYS by Yujia Ding, CSRRI/MRCAT

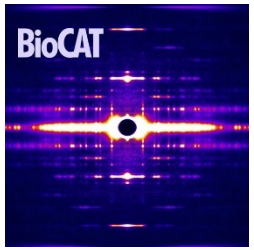


Optical performance summary

	APS (measured)	APS-U (perfect)	APS-U (expected)	APS-U (measured)
Sagittal focus (H)	120 μm	5.9 μm	5.9 μm	16 μm
Mirror focus (V)	18 μm	3.0 μm	14.3 μm	25 μm
Flux (12 keV)	$3*10^{13}$ ph/s	$5.5*10^{13}$ ph/s	$5.5*10^{13}$ ph/s	$5.5*10^{13}$ ph/s*
CRL, long (VxH)	4 x 23 μm^2	0.63 x 0.92 μm^2	2.9 x 0.95 μm^2	2.9 x 1.4 μm^2
CRL, short (VxH)	0.5 x 5 μm^2	0.15 x 0.22 μm^2	0.72 x 0.22 μm^2	0.99 x 0.2 μm^2

*Extrapolated based on ring current of measurement and upgrade target ring current

All values for 48 bunch timing mode



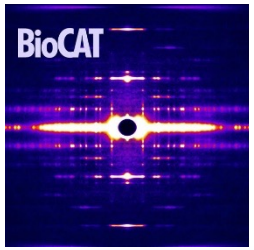
Optical performance summary

7.5x better

	APS (measured)	APS-U (perfect)	APS-U (expected)	APS-U (measured)
Sagittal focus (H)	120 μm	5.9 μm	5.9 μm	16 μm
Mirror focus (V)	18 μm	3.0 μm	14.3 μm	25 μm
Flux (12 keV)	$3*10^{13}$ ph/s	$5.5*10^{13}$ ph/s	$5.5*10^{13}$ ph/s	$5.5*10^{13}$ ph/s*
CRL, long (VxH)	4 x 23 μm^2	0.63 x 0.92 μm^2	2.9 x 0.95 μm^2	2.9 x 1.4 μm^2
CRL, short (VxH)	0.5 x 5 μm^2	0.15 x 0.22 μm^2	0.72 x 0.22 μm^2	0.99 x 0.2 μm^2

*Extrapolated based on ring current of measurement and upgrade target ring current

All values for 48 bunch timing mode



Optical performance summary

	APS (measured)	APS-U (perfect)	APS-U (expected)	APS-U (measured)
Sagittal focus (H)	120 μm	5.9 μm	5.9 μm	16 μm
Mirror focus (V)	18 μm	3.0 μm	14.3 μm	25 μm
Flux (12 keV)	$3*10^{13}$ ph/s	$5.5*10^{13}$ ph/s	$5.5*10^{13}$ ph/s	$5.5*10^{13}$ ph/s*
CRL, long (VxH)	4 x 23 μm^2	0.63 x 0.92 μm^2	2.9 x 0.95 μm^2	2.9 x 1.4 μm^2
CRL, short (VxH)	0.5 x 5 μm^2	0.15 x 0.22 μm^2	0.72 x 0.22 μm^2	0.99 x 0.2 μm^2

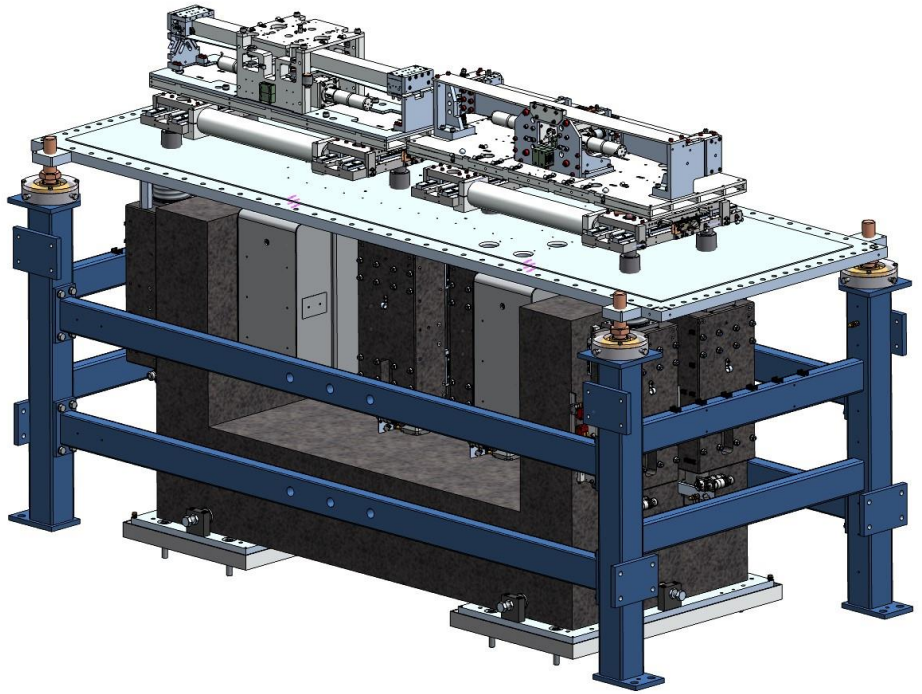
16x (H) better

*Extrapolated based on ring current of measurement and upgrade target ring current

All values for 48 bunch timing mode

New BioCAT optics

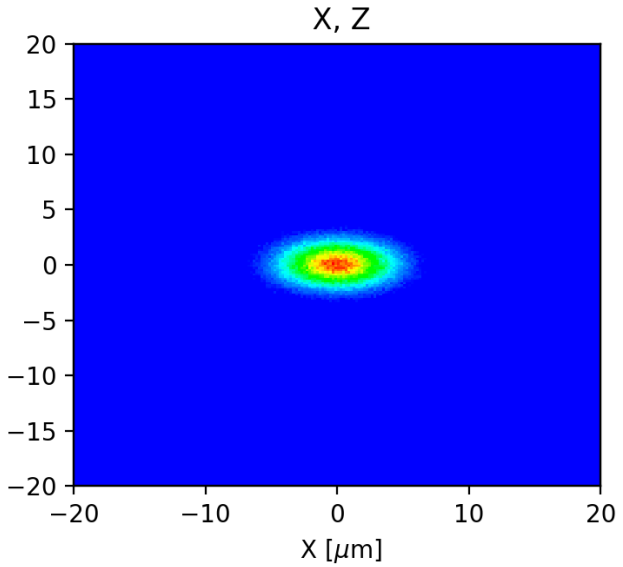
- BioCAT's optics are now the limiting factor in beam quality
  - Optics are mostly original to the beamline, nearly 30 years old
- In August 2024, the NIH approved $2 million in supplementary funds to upgrade current optics to take full advantage of APS-U
  - New KB-style horizontal and vertical focusing mirrors
  - New monochromator with both Silicon (high energy resolution) and multilayer (high flux) optics
- Project is underway and expected installation is early to mid 2026



Optical performance post APS-U

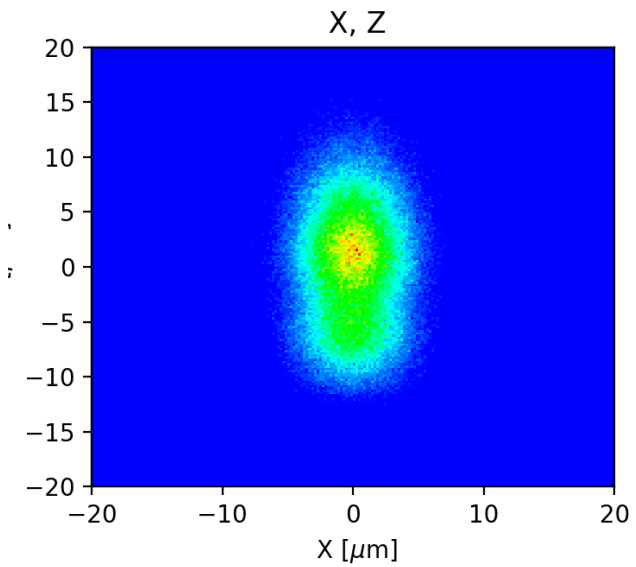
- Simulated beam shape/flux with OASYS at 64 m at 12 keV (Yujia Ding)
- Expected flux: ~6*10^{13} ph/s @ 12 keV

Perfect upstream optics



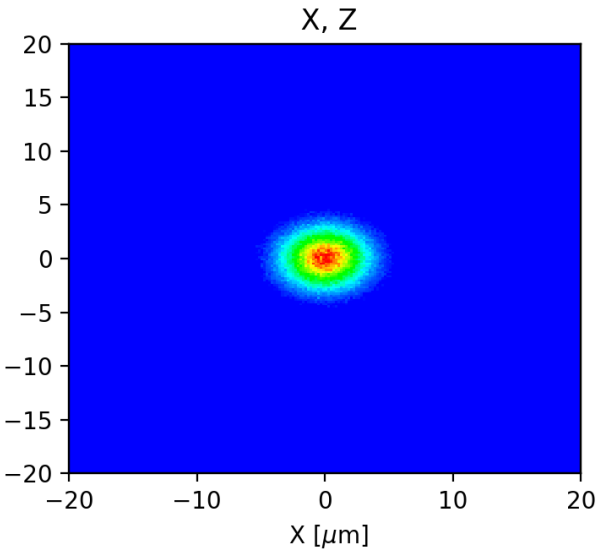
H: 5.9 μm
V: 3.0 μm

Current upstream optics



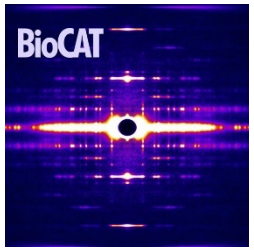
H: 5.9 μm
V: 14.3 μm

Upgraded optics



H: 4.7 μm
V: 3.9 μm

Simulations in OASYS by Yujia Ding, CSRRI/MRCAT



Optical performance summary

	APS (measured)	APS-U (perfect)	APS-U (measured)	APS-U (new optics)
Sagittal focus (H)	120 μm	5.9 μm	16 μm	
Mirror focus (V)	18 μm	3.0 μm	25 μm	3.9 μm
Mirror focus (H)		4.3 μm		4.7 μm
Flux (12 keV)	$3*10^{13}$ ph/s	$5.5*10^{13}$ ph/s	$5.5*10^{13}$ ph/s*	$5.5*10^{13}$ ph/s
Flux (ML, 12 keV)		$4*10^{15}$ ph/s		$4*10^{15}$ ph/s
CRL, long (VxH)	4 x 23 μm^2	0.63 x 0.92 μm^2	2.9 x 1.4 μm^2	0.70 x 1.0 μm^2
CRL, short (VxH)	0.5 x 5 μm^2	0.15 x 0.22 μm^2	0.99 x 0.2 μm^2	0.17 x 0.25 μm^2

*Extrapolated based on ring current of measurement and upgrade target ring current

All values for 48 bunch timing mode

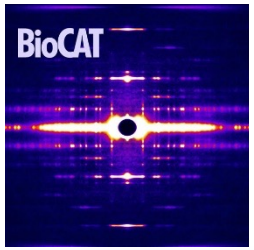
Optical performance summary

	APS (measured)	APS-U (perfect)	APS-U (measured)	APS-U (new optics)
Sagittal focus (H)	120 μm	5.9 μm	16 μm	
Mirror focus (V)	18 μm	3.0 μm	25 μm	3.9 μm
Mirror focus (H)		4.3 μm		4.7 μm
Flux (12 keV)	$3*10^{13}$ ph/s	$5.5*10^{13}$ ph/s	$5.5*10^{13}$ ph/s*	$5.5*10^{13}$ ph/s
Flux (ML, 12 keV)		$4*10^{15}$ ph/s		$4*10^{15}$ ph/s
CRL, long (VxH)	4 x 23 μm^2	0.63 x 0.92 μm^2	2.9 x 1.4 μm^2	0.70 x 1.0 μm^2
CRL, short (VxH)	0.5 x 5 μm^2	0.15 x 0.22 μm^2	0.99 x 0.2 μm^2	0.17 x 0.25 μm^2

80x better

*Extrapolated based on ring current of measurement and upgrade target ring current

All values for 48 bunch timing mode



Optical performance summary

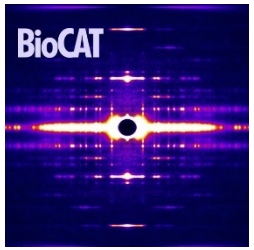
9.6x (V)
3.1x (H)
better

	APS (measured)	APS-U (perfect)	APS-U (measured)	APS-U (new optics)
Sagittal focus (H)	120 μm	5.9 μm	16 μm	
Mirror focus (V)	18 μm	3.0 μm	25 μm	3.9 μm
Mirror focus (H)		4.3 μm		4.7 μm
Flux (12 keV)	$3*10^{13}$ ph/s	$5.5*10^{13}$ ph/s	$5.5*10^{13}$ ph/s*	$5.5*10^{13}$ ph/s
Flux (ML, 12 keV)		$4*10^{15}$ ph/s		$4*10^{15}$ ph/s
CRL, long (VxH)	4 x 23 μm^2	0.63 x 0.92 μm^2	2.9 x 1.4 μm^2	0.70 x 1.0 μm^2
CRL, short (VxH)	0.5 x 5 μm^2	0.15 x 0.22 μm^2	0.99 x 0.2 μm^2	0.17 x 0.25 μm^2

*Extrapolated based on ring current of measurement and upgrade target ring current

And better beam shape!

All values for 48 bunch timing mode



Summary

- APS-U provides smaller, brighter beams and a state-of-the-art facility for BioCAT
- Measured beam size and flux is in line with expected APS-U values
  - ~8x decrease in horizontal size
  - ~4-20x decrease in microfocus beam size
  - ~2x increase in flux
- New (ongoing) optics upgrade will allow BioCAT to take full advantage of APS-U and provide the best possible beams
  - Expected ~3-10x decrease in beam size with main optics
  - Expected ~4x decrease in microfocus beam size
  - Beam shape is significantly improved
  - Up to 80x increase in flux