

Ground calibration of X-ray Mirror Assembly (XMA) for XRISM

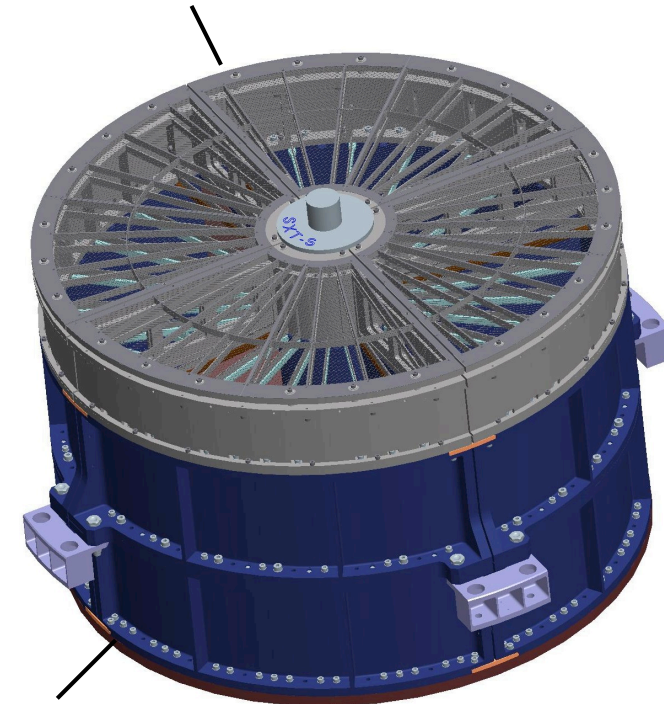


Takayuki Hayashi, Takashi Okajima,
Rozenn Boissay-Malaquin, Keisuke Tamura (NASA's GSFC)

X-ray Mirror Assembly (XMA)

- X-ray optics for Resolve&Xtend
 - XMA of Resolve → Resolve-XMA
 - XMA of Xtend → Xtend-XMA
- Almost the same design as ASTRO-H SXT's
- Wolter-I type optics (with conical approximation)
- X-rays are reflected by primary and secondary reflectors, and focus on detector
- Aperture: 45 cm
- Focal length: 5.6 m
- Reflector: 150-300 μm aluminum sheet + Au reflective surface (203 reflectors nested)
 - Mirror part consist of 4 quadrants (QTs)
- 203 reflectors are nested

Precollimator (PC)
(Stray baffle)

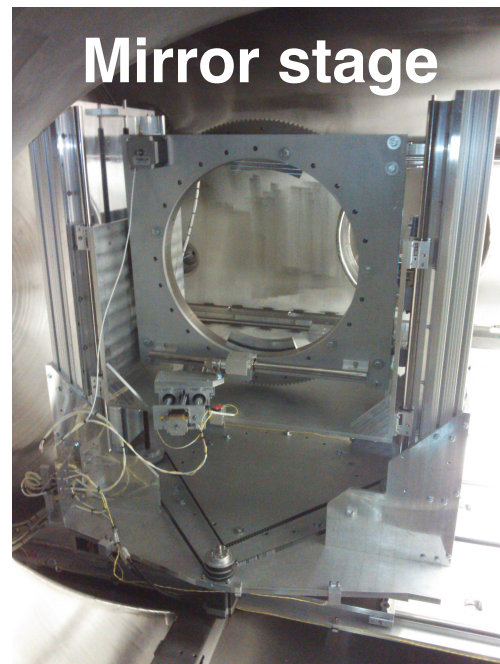
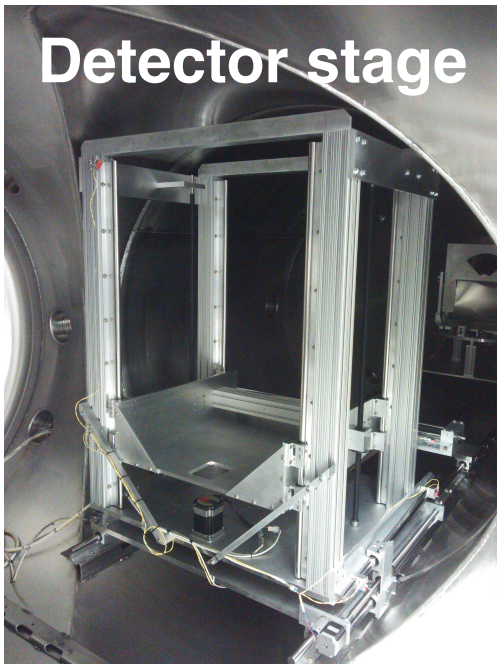
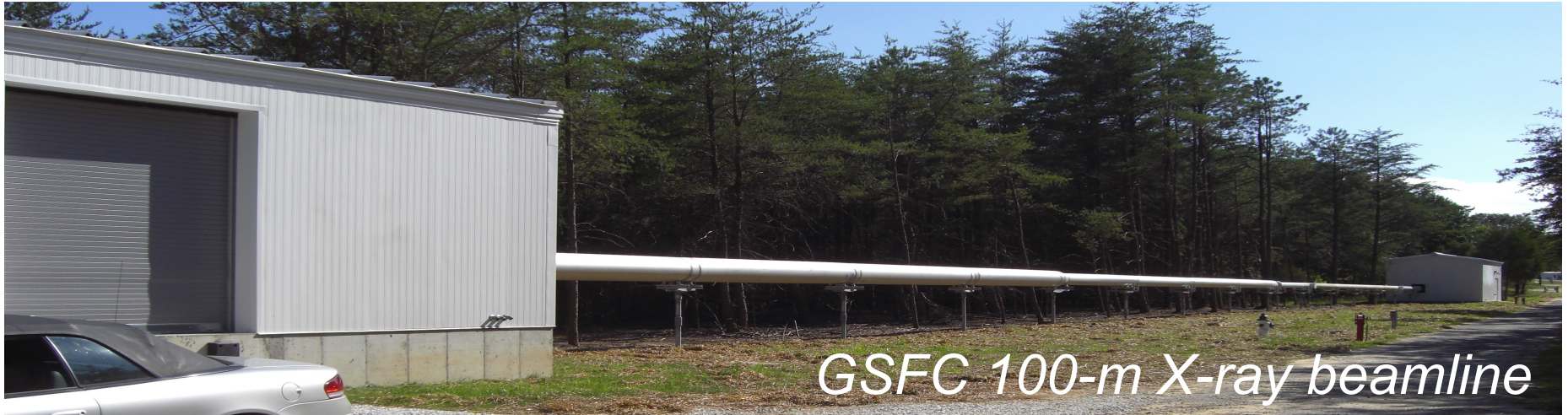


Mirror part

XMA ground calibration took place at

X-ray beamline of NASA's Goddard Space Flight Center (GSFC)

Upgrade of GSFC X-ray beamline for XMA ground calibration



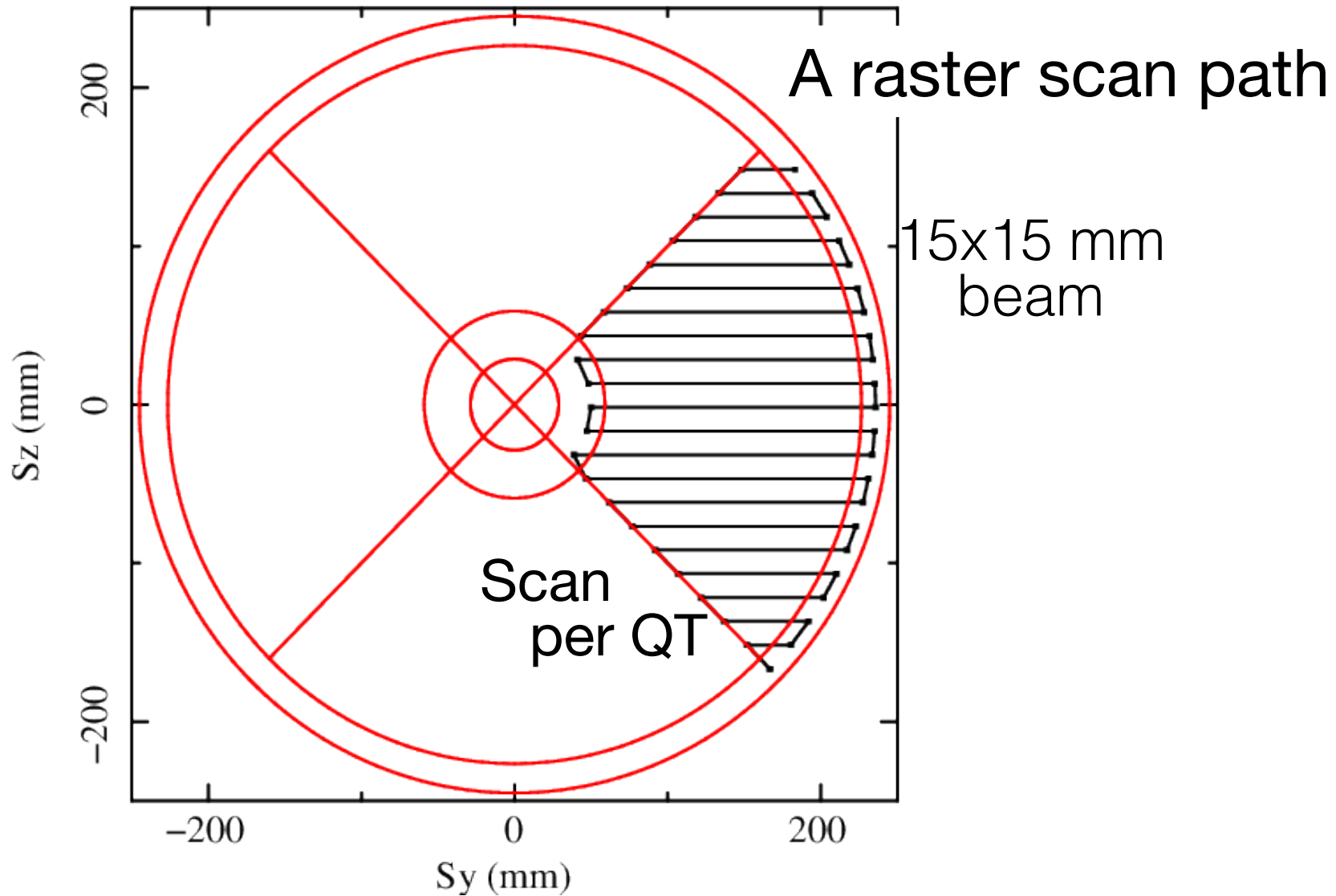
Newly introduced

- Big chamber for movable mirror & detector stages
- Rigaku X-ray generator
- Crystal monochromator
- Four-jaw slit

Measurement

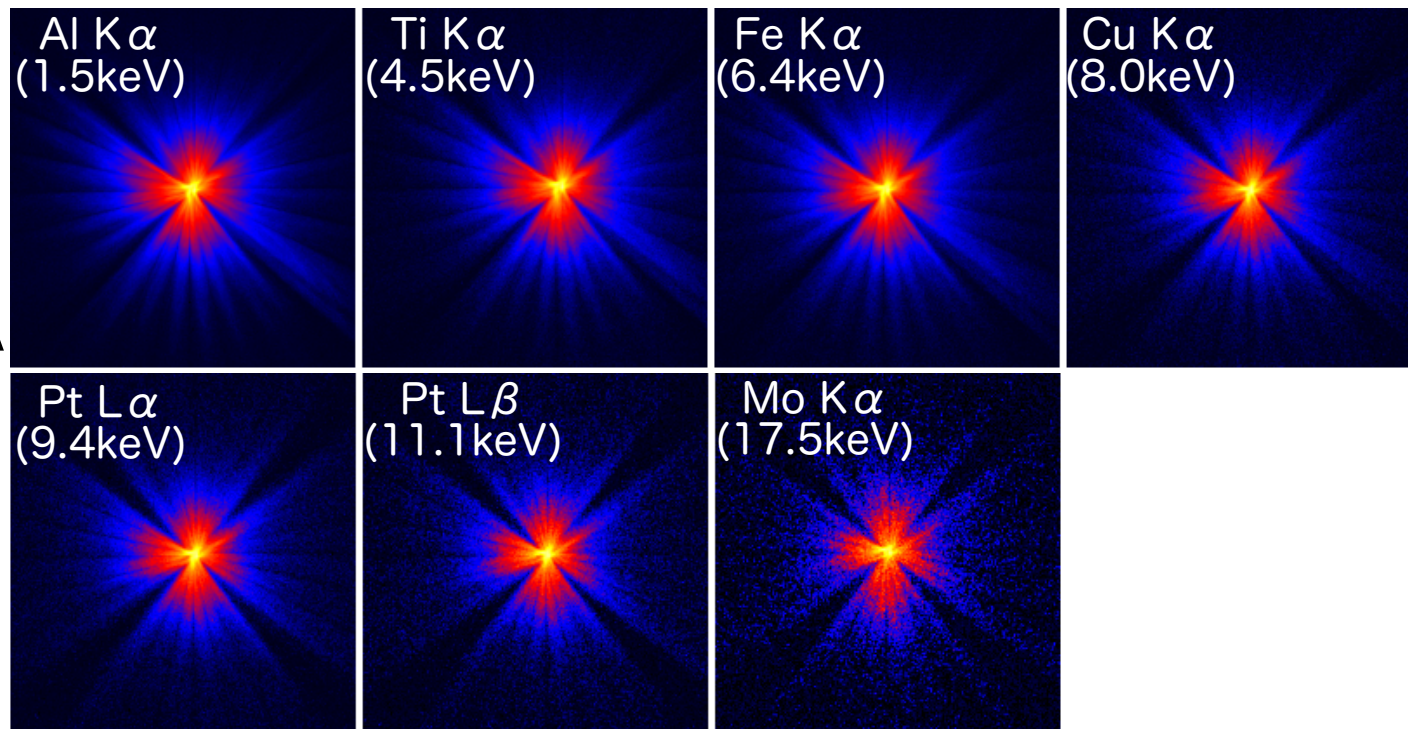
- X-ray energy: 1.5, 4.5, 6.4, 8.0, 11.1, 9.4, 17.5, (22.2) keV
(Corresponding source material: Al, Ti, Fe, Cu, Pt, Mo, (Ag))
- Monochromator
 - 1.5 keV (Al): Al metal filter
 - Other energies: Si(111) or Si(220)
- Source size: 0.6 or 1.0 arcsec
- Detector → CCD → Point Spread Function (PSF) & Effective Area (EA)
- Pencil beam of 15x15 mm or 10x10 mm
 - small diverging angle → correct EA
- Distance between mirror and detector: Focusing distance
considering finite distance between source and mirror
- Scans
 - Mirror&detector are synchronously moved
 - so that the beam scan across the mirror aperture
 - Raster scan: stages move during exposure → Time-saving
 - Local spot scan: stages stop during exposure
 - Time-consuming but local performance

Raster scan measurement

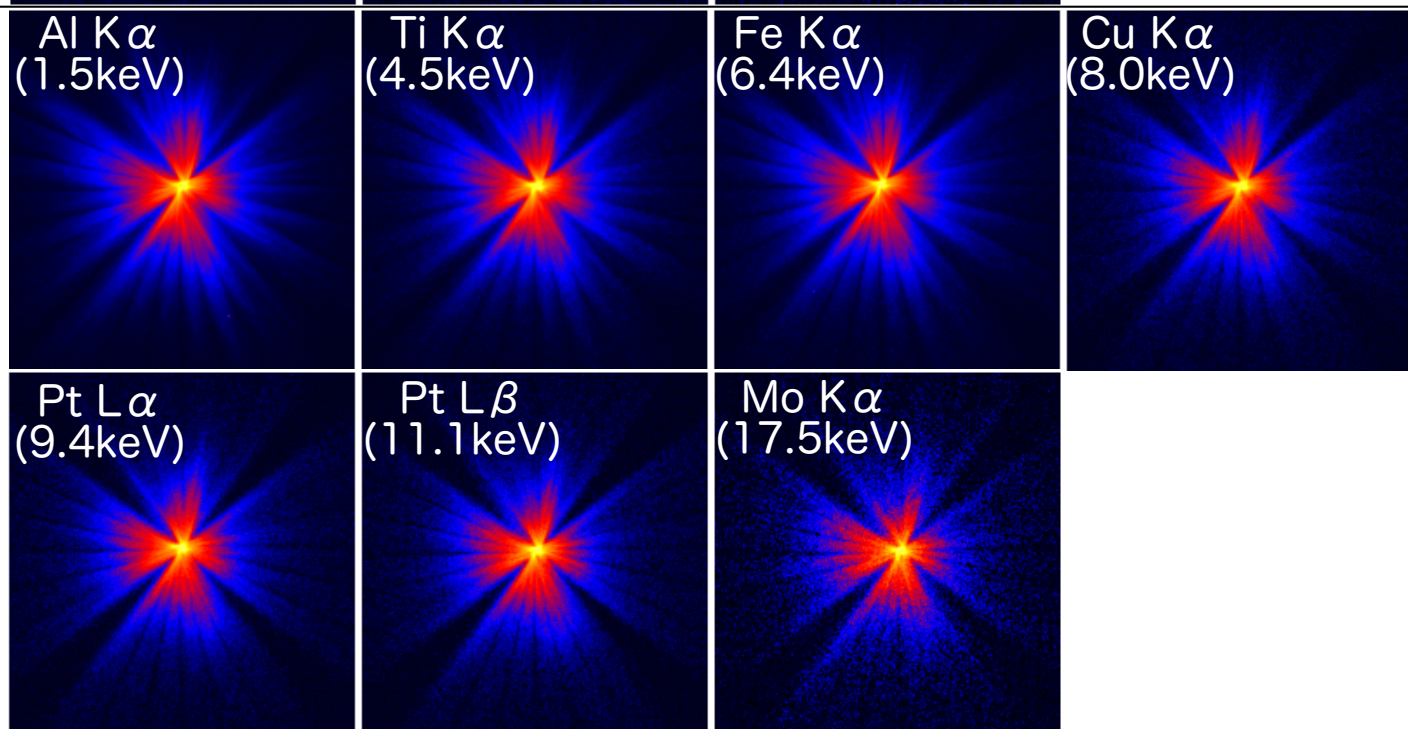


XMA Images (2D PSF)

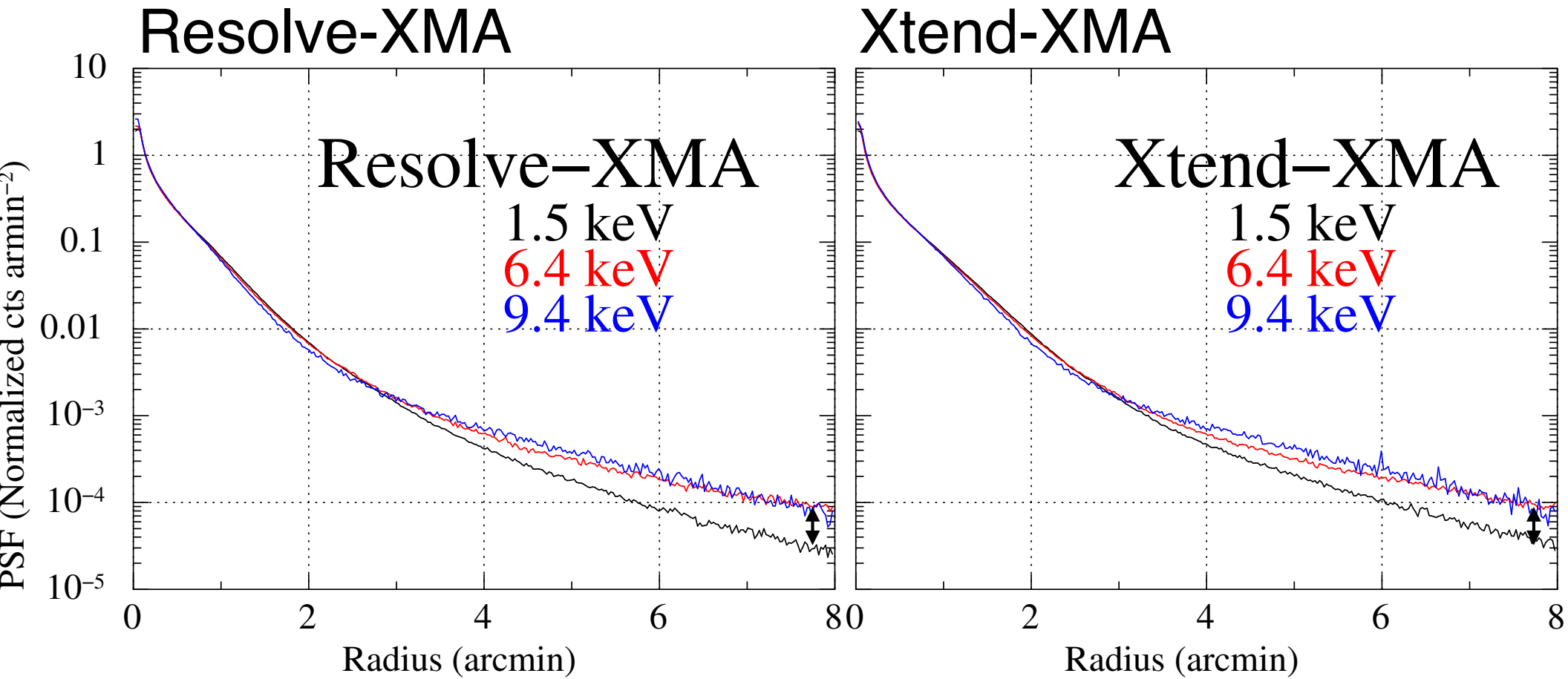
Resolve-XMA



Xtend-XMA



1D PSF



- Lower PSF tail at 1.5 keV

Half-Power Diameter (HPD)

Resolve-XMA

HPD (arcmin)	1.5keV	4.5keV	6.4keV	8.0keV	9.4keV	11.1keV	17.5keV
Total	1.29	1.30	1.30	1.28	1.22	1.19	1.24
Q1	1.26	1.29	1.27	1.28	1.26	1.30	1.48
Q2	1.50	1.56	1.52	1.54	1.47	1.34	1.24
Q3	1.13	1.13	1.15	1.11	1.08	1.10	1.28
Q4	1.30	1.28	1.30	1.21	1.08	1.13	1.14

Xtend-XMA

HPD (arcmin)	1.5keV	4.5keV	6.4keV	8.0keV	9.4keV	11.1keV	17.5keV
Total	1.47	1.46	1.47	1.47	1.40	1.37	1.37
Q1	1.50	1.41	1.48	1.55	1.50	1.47	1.40
Q2	1.62	1.62	1.63	1.60	1.57	1.55	1.81
Q3	1.47	1.45	1.46	1.39	1.29	1.20	1.18
Q4	1.21	1.22	1.25	1.23	1.19	1.13	1.06

*Requirement for HPD: 1.7 arcmin

Effective area

Error: 68% statistical error

Resolve-XMA (in circle of $r = 8$ arcmin)

	1.5 keV	4.5 keV	6.4 keV	8.0 keV	9.4 keV	11.1 keV	17.5 keV
Total	584.7 ± 0.4	434.7 ± 0.6	416.0 ± 0.6	345.3 ± 0.8	265.8 ± 1.4	191 ± 1.7	43.0 ± 1.1
Q1	145.6 ± 0.2	109.2 ± 0.3	103.6 ± 0.3	85.7 ± 0.4	65.8 ± 0.5	46.3 ± 0.5	10.3 ± 0.3
Q2	148.6 ± 0.2	112.4 ± 0.3	105.5 ± 0.3	88.0 ± 0.4	67.3 ± 0.5	47.6 ± 0.5	10.4 ± 0.3
Q3	147.8 ± 0.2	109.5 ± 0.3	105.8 ± 0.3	86.3 ± 0.4	66.5 ± 0.5	48.3 ± 0.5	11.2 ± 0.3
Q4	142.7 ± 0.2	103.7 ± 0.3	101.1 ± 0.3	85.4 ± 0.4	66.3 ± 0.5	49.3 ± 0.5	11.2 ± 0.3

*Confirmed XMA has some EA at 22.2 keV

Xtend-XMA (in circle of $r = 8$ arcmin)

	1.5 keV	4.5 keV	6.4 keV	8.0 keV	9.4 keV	11.1 keV	17.5 keV
Total	589.4 ± 0.4	441.5 ± 0.6	422.2 ± 0.6	349.2 ± 0.8	268.2 ± 1.5	192.7 ± 1.6	42.5 ± 1.1
Q1	147.3 ± 0.2	109.9 ± 0.3	106.0 ± 0.3	87.8 ± 0.4	66.5 ± 0.5	48.9 ± 0.5	11.2 ± 0.3
Q2	148.3 ± 0.2	112.6 ± 0.3	107.6 ± 0.3	89.0 ± 0.4	69.0 ± 0.5	48.9 ± 0.5	10.9 ± 0.3
Q3	147.1 ± 0.2	110.0 ± 0.3	105.0 ± 0.3	86.6 ± 0.4	66.3 ± 0.5	47.3 ± 0.5	10.0 ± 0.3
Q4	146.7 ± 0.2	109.0 ± 0.3	103.6 ± 0.3	85.8 ± 0.4	66.4 ± 0.5	47.8 ± 0.5	10.5 ± 0.3

EA cross-calibration with measurement at ISAS in Japan

- Measurement at 30m X-ray beam line of ISAS in Japan after delivery

Resolve-XMA @ 6.4 keV (in circle of $r = 3.68$ arcmin)

	Q1	Q2	Q3	Q4	Total
ISAS*	99.5 ± 0.5	102.2 ± 0.6	103.2 ± 0.5	97.1 ± 0.4	402.0 ± 1.0
GSFC#	99.8 ± 0.3	101.7 ± 0.3	102.8 ± 0.3	96.3 ± 0.3	400.6 ± 0.6
Ratio	1.00 ± 0.01	1.00 ± 0.01	1.00 ± 0.01	1.01 ± 0.01	1.003 ± 0.003

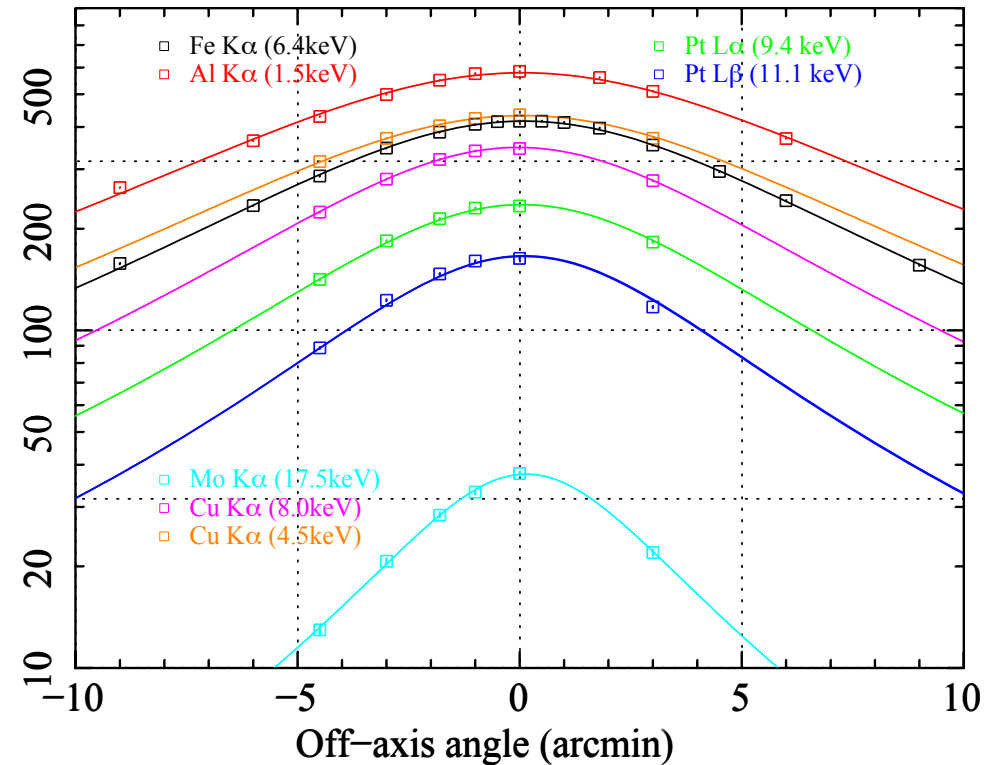
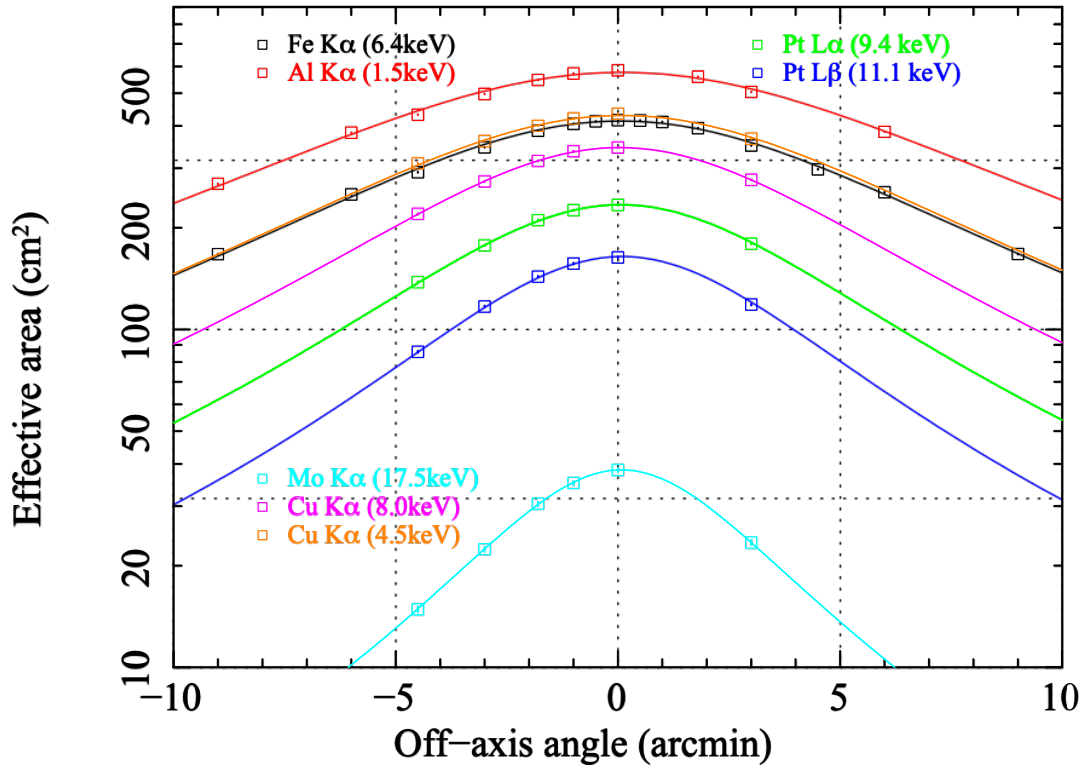
*Proportional counter
CCD

Error: 68% statistical error

- Very consistent result

Confirmed correctness of pencil beam measurement of EA

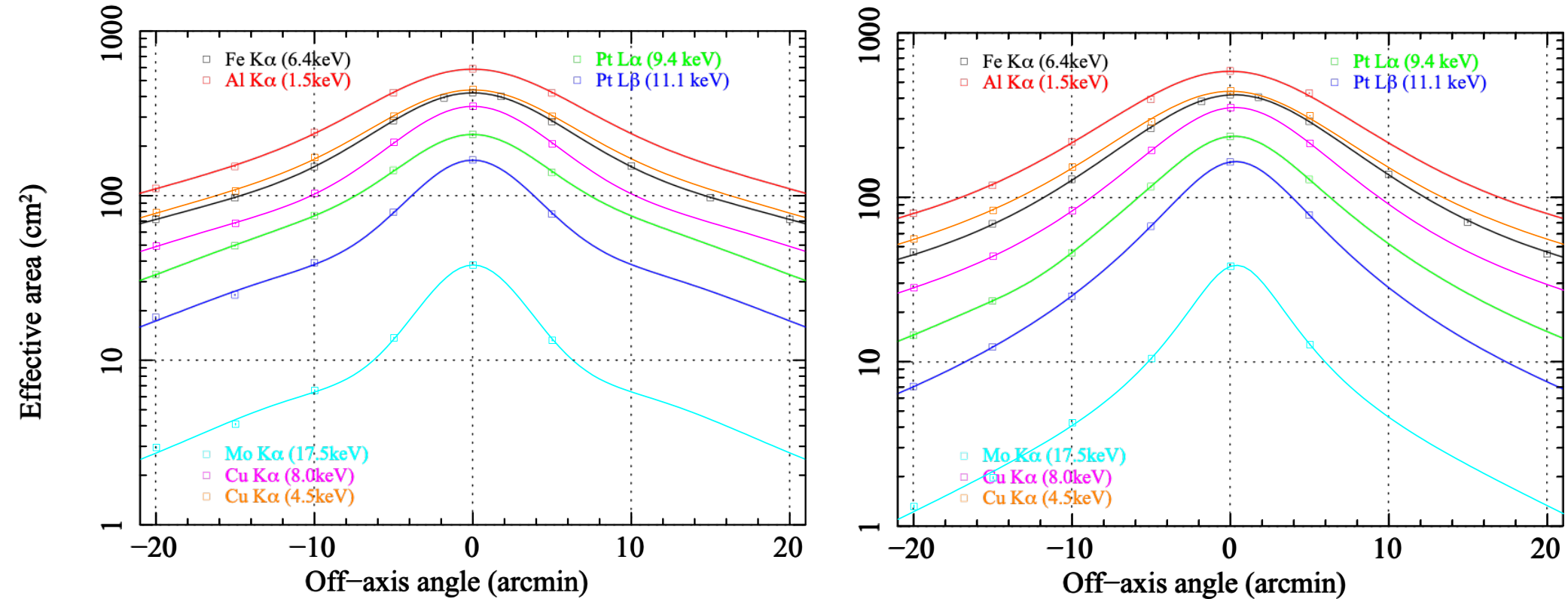
Vignetting of Resolve-XMA



Measurement positions

- 1.5 keV: at 1', 1.8', 3', 4.5', 6' and 9' in 2 azimuthal directions (a QT boundary and a mid-QT) or 1.8', 3' and 6' in 8 azimuthal directions (every 45 deg)
 - 6.4 keV: at 0.5', 1', 1.8', 3', 6' and 9' in 8 azimuthal directions (every 45 deg)
 - 4.5, 8.0, 9.4, 11.1 and 17.5 keV: at 1', 1.8', 3', 4.5', 6' and 9' in 2 azimuthal directions (a QT boundary and a mid-QT)
- Note: images were acquired at all the positions as well

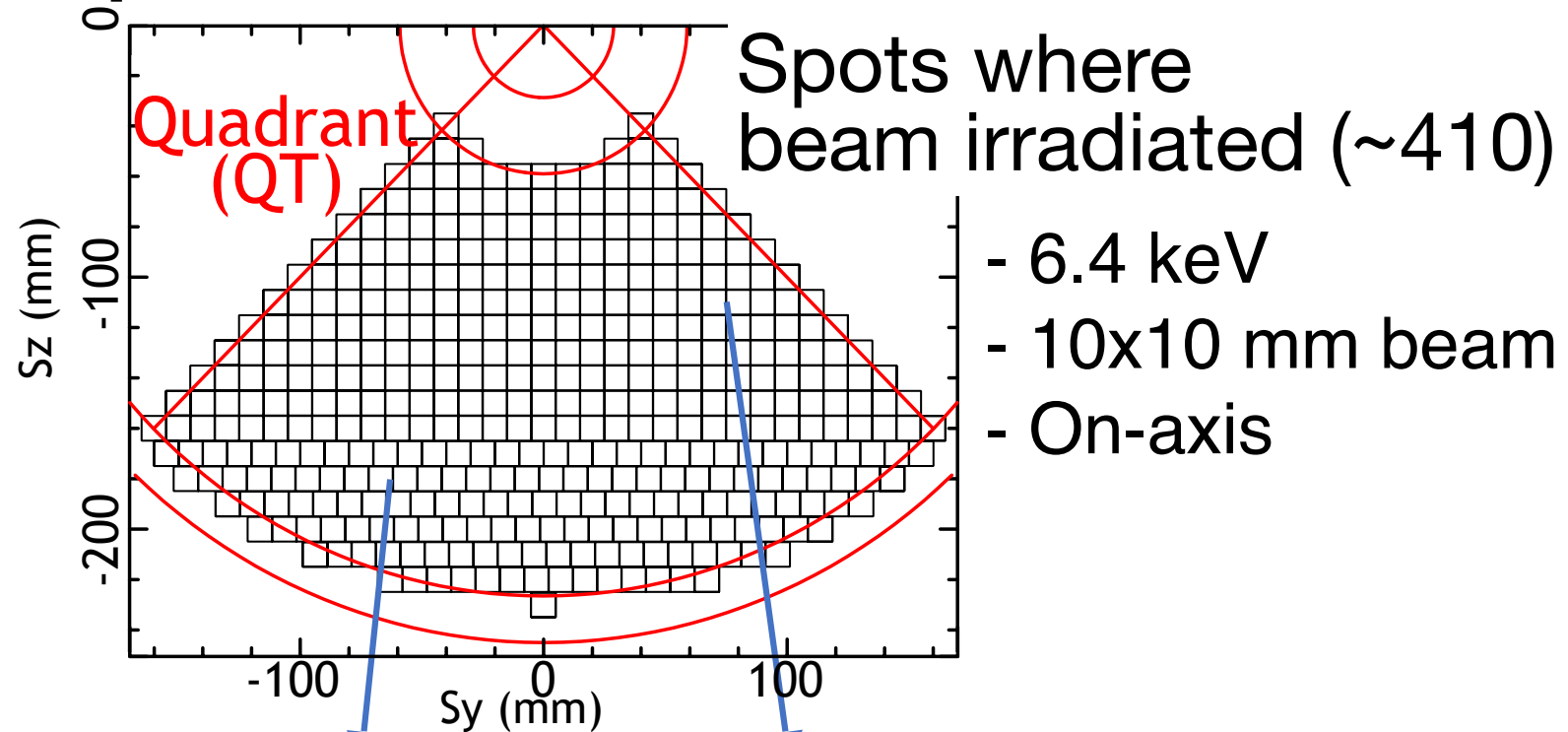
Vignetting of Xtend-XMA



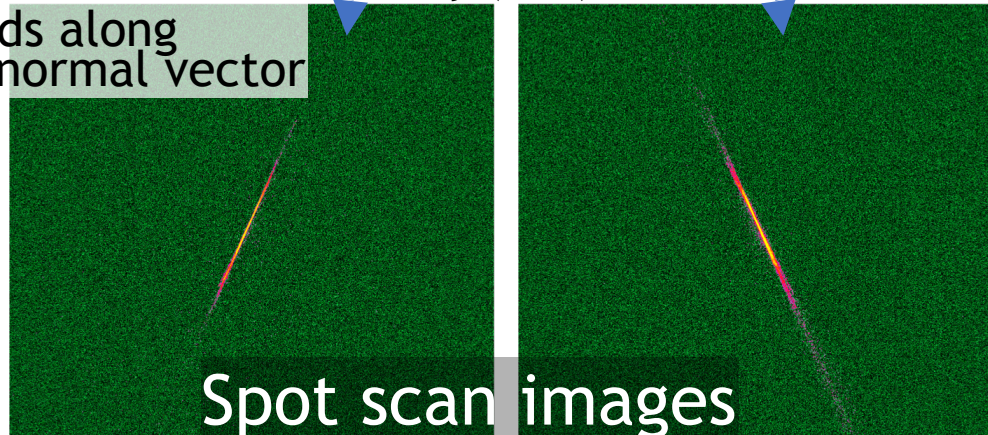
Measurement positions

- 6.4 keV: at 2', 5', 10', 15' and 20' in 8 azimuthal directions (every 45 deg)
 - 1.5, 4.5, 8.0, 9.4, 11.1 and 17.5 keV: at 5', 10', 15' and 20' in 2 azimuthal directions (a QT boundary and a mid-QT)
- Note: images were acquired at all the positions as well

Local spot scan measurement



Extends along foil's normal vector



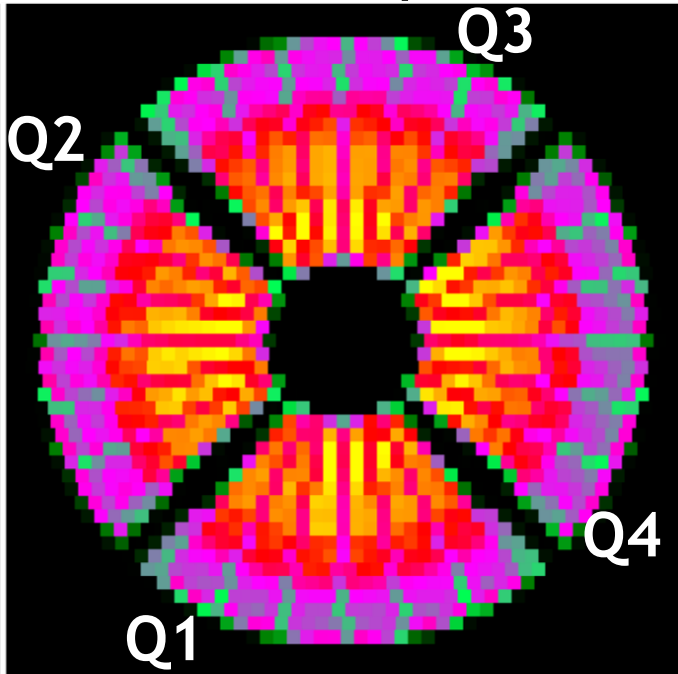
Spot scan images

Performance maps of Resolve-XMA

- Number of photons

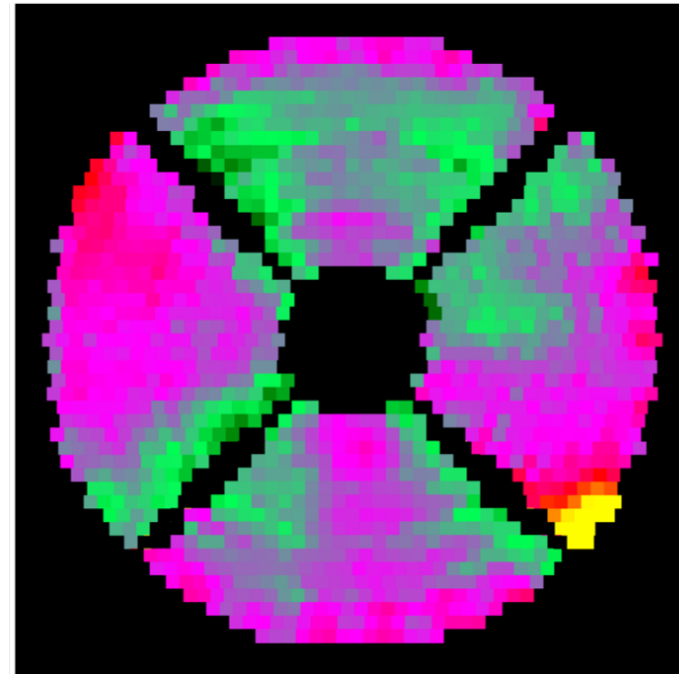
- Image center position

- Image profile width



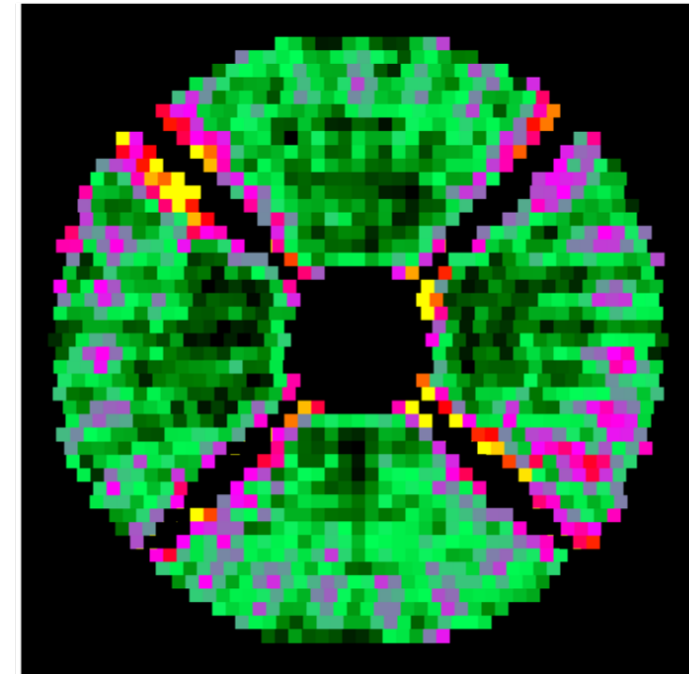
0 1 2 3 4
Number of photon ($\times 10^4$)

↓
Effective area



-1 0 1 2 3
Image center shift (arcmin)
Shorter FL ← → Longer FL

↓
Focal length
↓
Foil misalignment in tilt



0.5 1 1.5 2 2.5
HPD (arcmin)

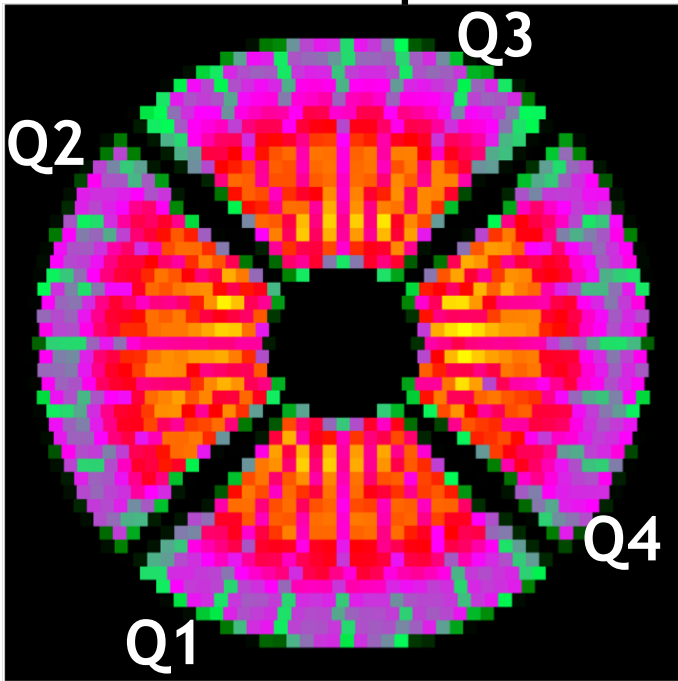
↓
Foil figure error

Performance maps of Xtend-XMA

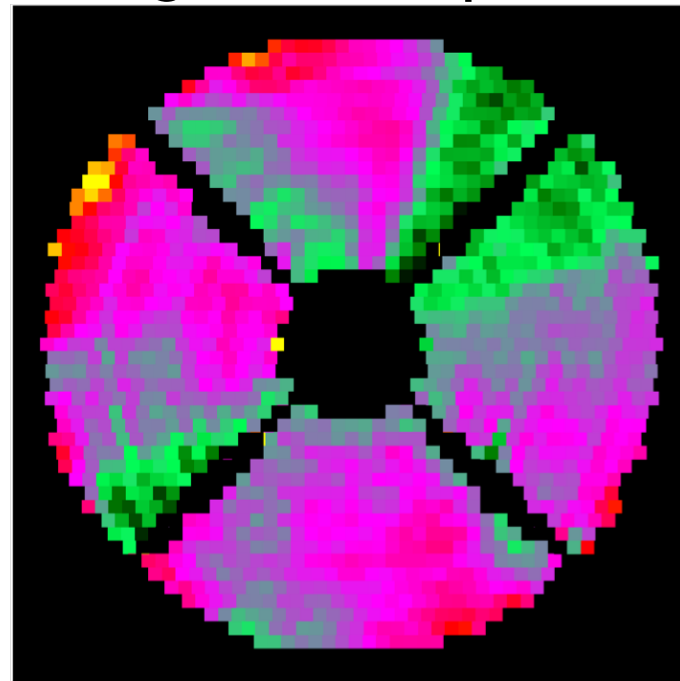
- Number of photons

- Image center position

- Image profile width



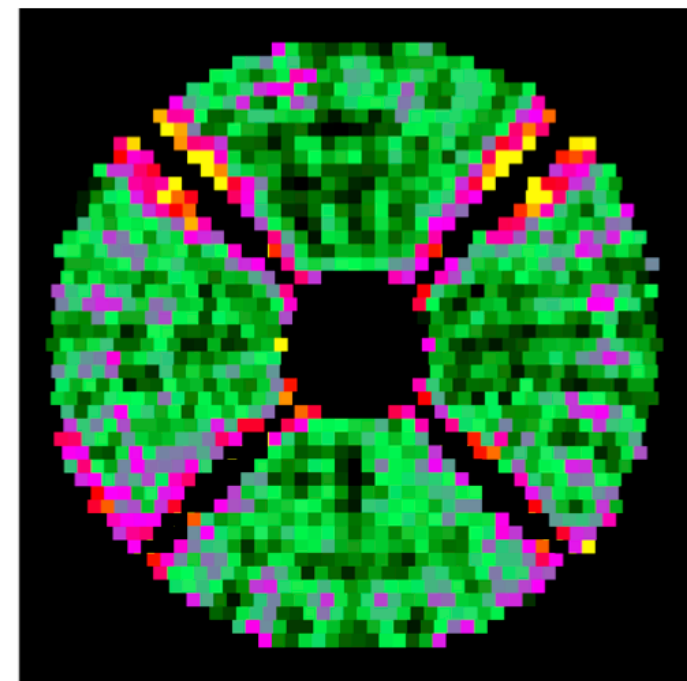
0 1.5 3 4.5 6
Number of photon ($\times 10^4$)



-1 0 1 2 3
Image center shift (arcmin)
Shorter FL \longleftrightarrow Longer FL

Focal length

Foil misalignment in tilt



0.5 1 1.5 2 2.5
HPD (arcmin)

Foil figure error

Effective area

CalDB is being developed with the spot scan data

Status of Calibration Data Base (CaIDB)

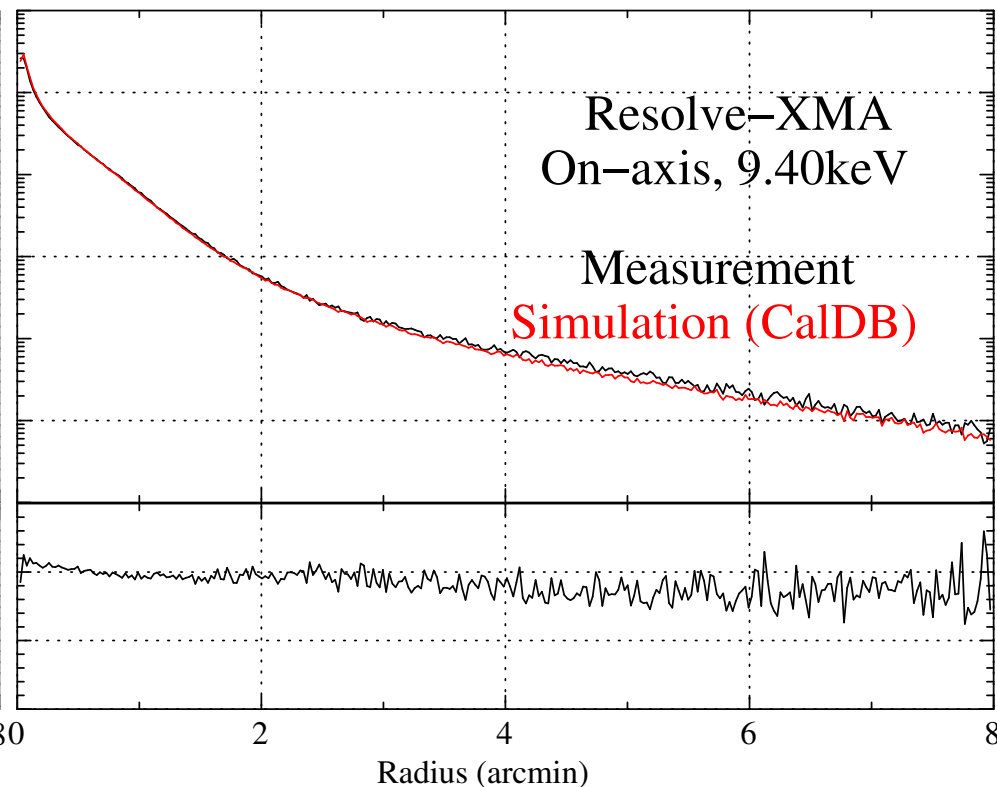
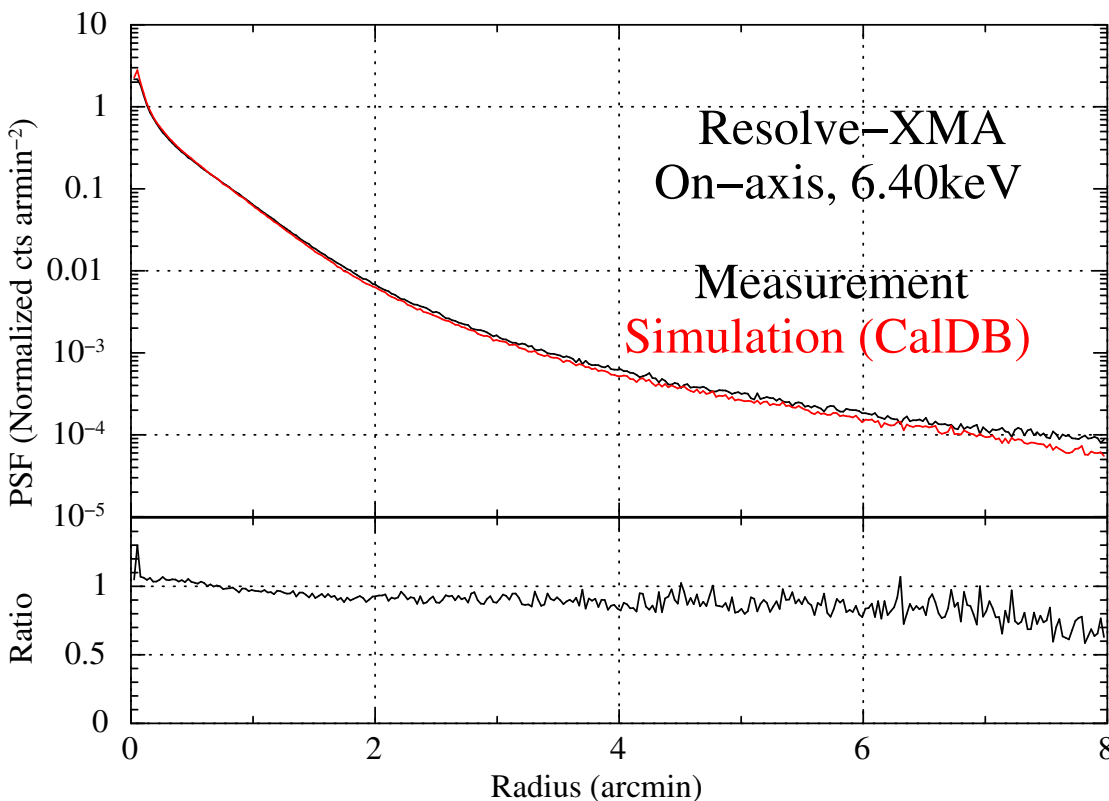
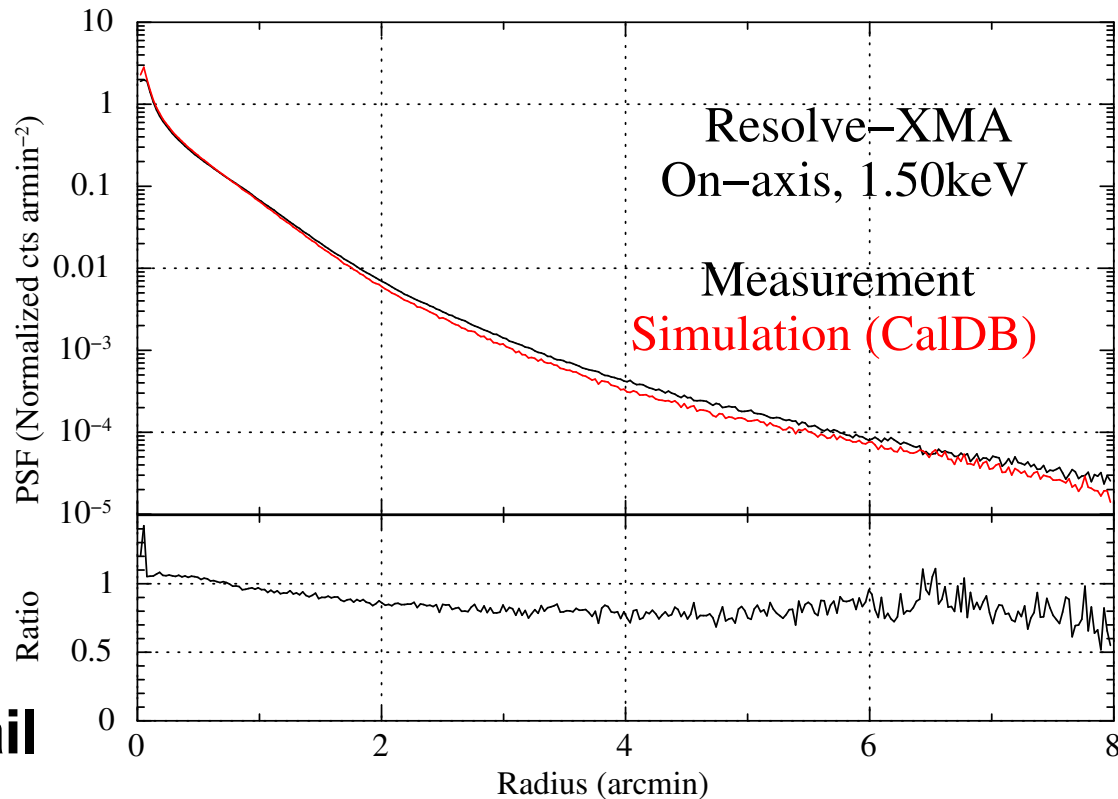
- Comparison between measurement and simulation using the current CaIDB files

Adjusted parameters [48 regions/QT]

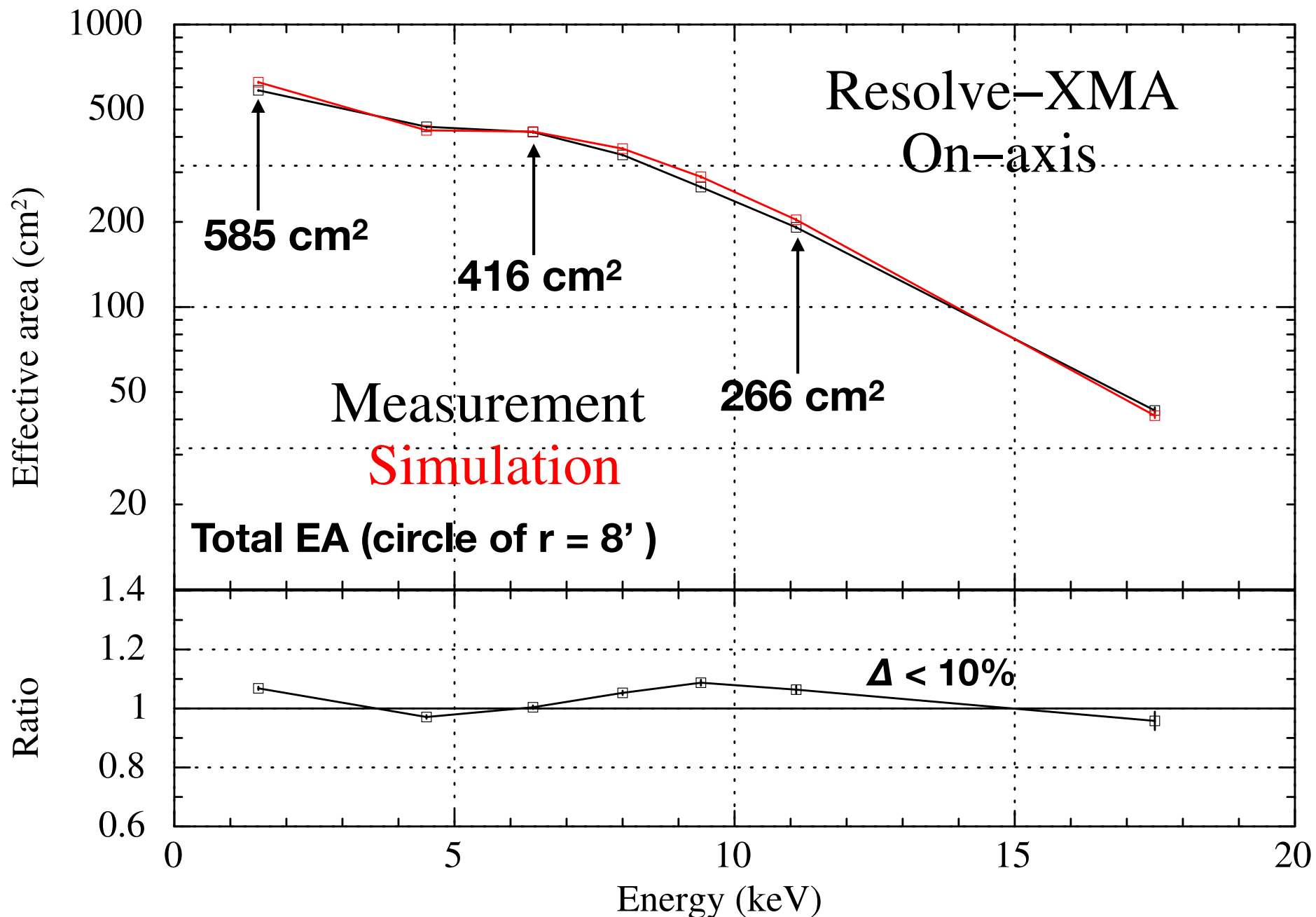
- Tilt angles of primary & secondary reflectors
- Shift of secondary reflector
- Scattering profile of primary and secondary reflectors
- Au reflective layer roughness & density
- QT tile angles & shift

Resolve-XMA on-axis PSF (Measurement vs simulation)

Well modeled including
the energy dependence in the tail



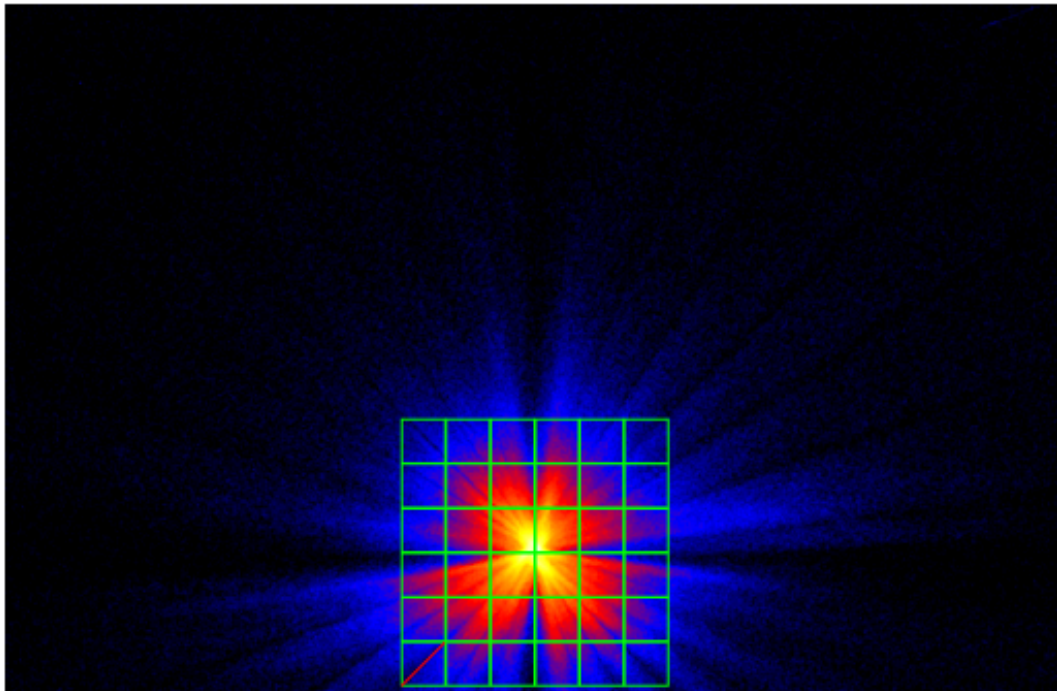
Resolve-XMA on-axis effective area (EA) (Measurement vs simulation)



Summary

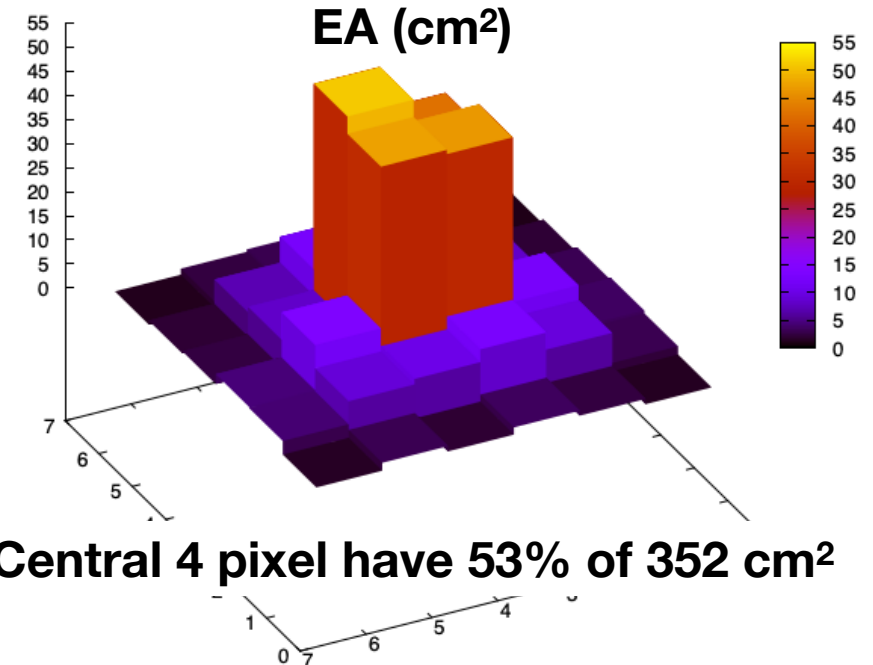
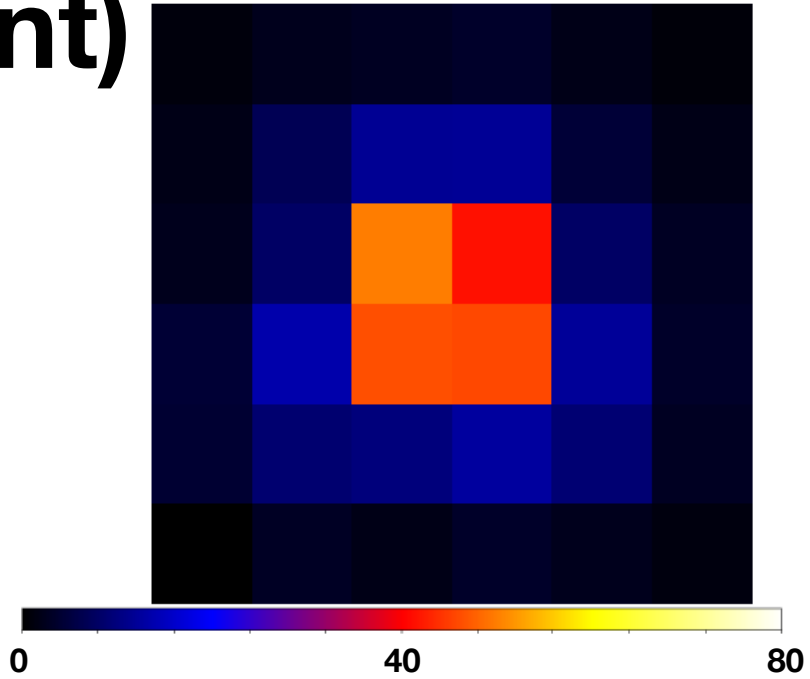
- GSFC 100m beamline was upgraded
 - XMA ground calibration was performed at GSFC X-ray beamline
 - On-axis effective area
 - Resolve-XMA: 585, 435, 416, 345, 266, 191 and 43 cm²
at 1.5, 4.5, 6.4, 8.0, 9.4, 11.1 and 17.5 keV, respectively
 - Xtend-XMA: 589, 442, 422, 349, 268, 193 and 43 cm²
at 1.5, 4.5, 6.4, 8.0, 9.4, 11.1 and 17.5 keV, respectively
 - HPD
 - Resolve-XMA: 1.2–1.3 arcmin in 1.5–17.5 keV
 - Xtend-XMA: 1.4–1.5 arcmin in 1.5–17.5 keV
 - Off-axis data was acquired with 6.4 keV
 - Resolve-XMA: at 0.5', 1', 1.8', 3, 4.5' 6' and 9'
 - Xtend-XMA: at 2', 5', 10', 15' and 20'
- some of off-axis angles above with 1.5, 4.5, 8.0, 9.4, 11.1 and 17.5 keV
- 10x10 mm local spot images were acquired
 - CalDB is being developed based on the ground calibration data

Resolve on-axis PSF (Measurement)



EA in Resolve FoV
= 352 cm² (mirror only)
→ 85% of total EA

*Not considering filters or quantum efficiency

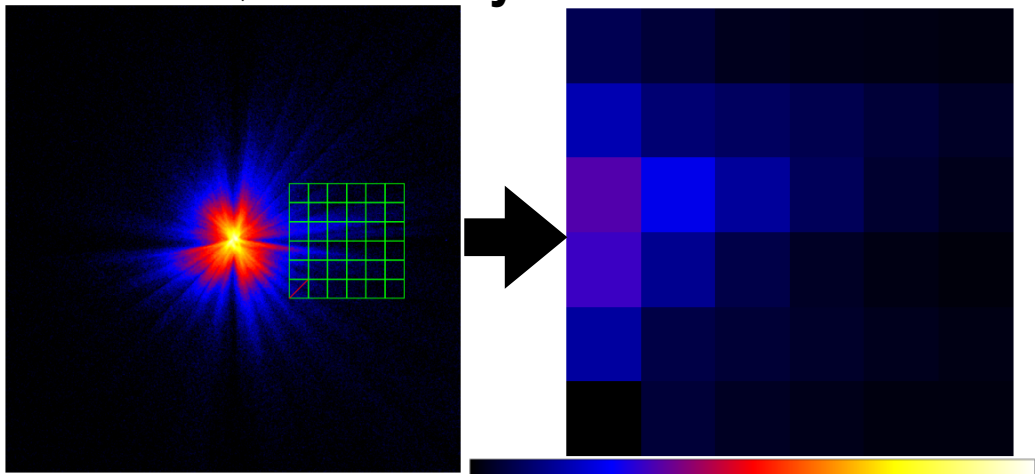


Central 4 pixel have 53% of 352 cm²

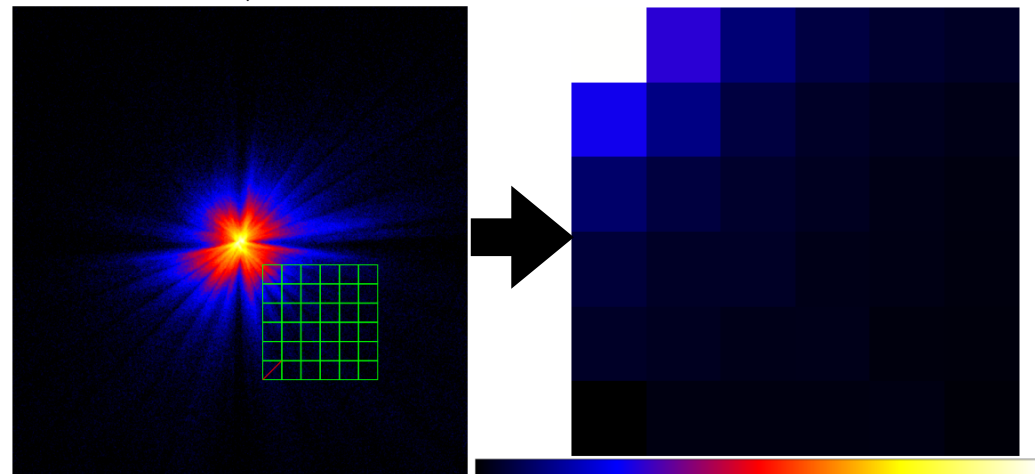
Resolve off-axis PSF (3' & 4.5')

(Measurement)

3'-off in QT boundary direction



3'-off in QT center direction

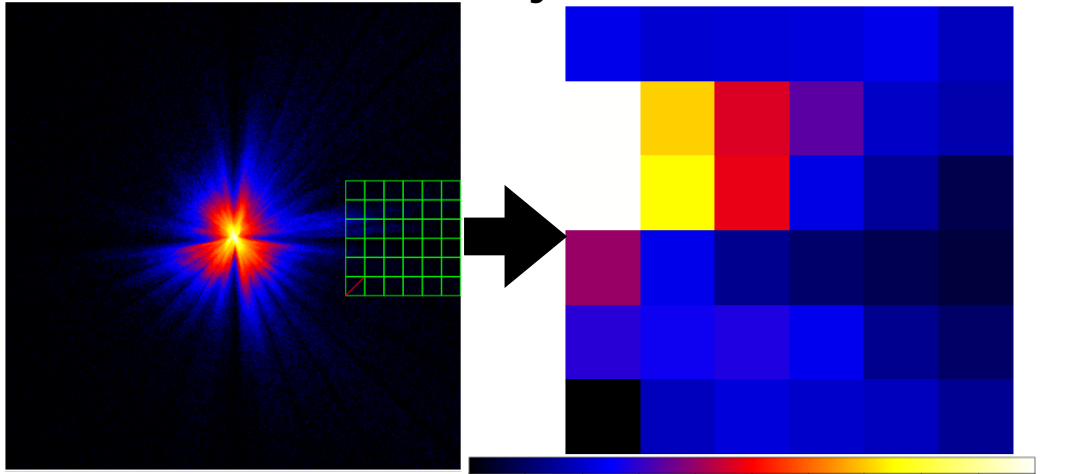


% of flux contamination from nearby source to on-axis source when nearby source is as bright as on-axis source

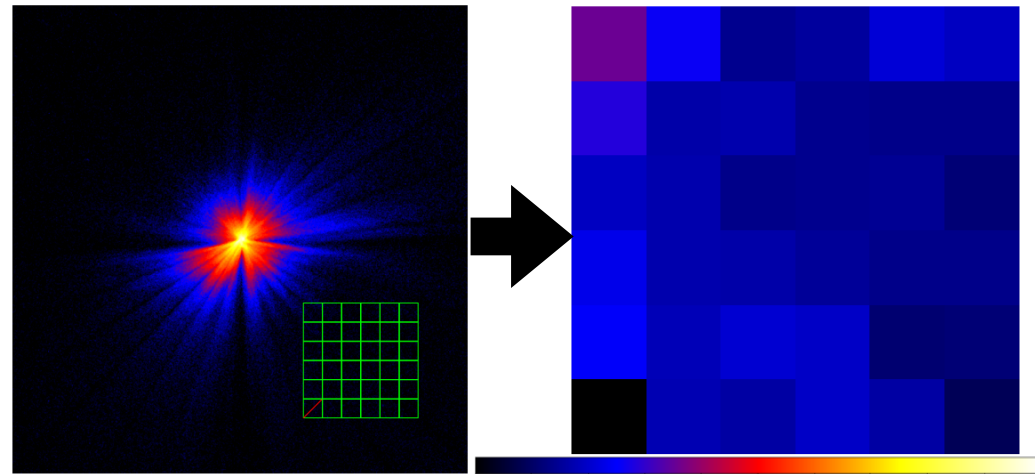
~ 3%

~ 3%

4.5'-off in QT boundary direction



4.5'-off in QT center direction



Scale is different in different off-axis angle

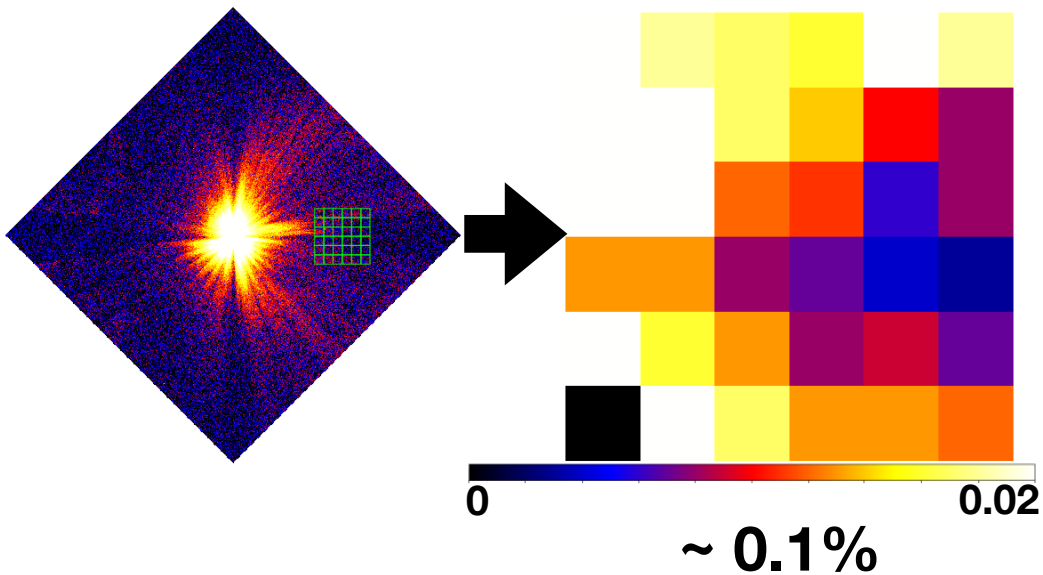
~ 0.5%

~ 0.3%

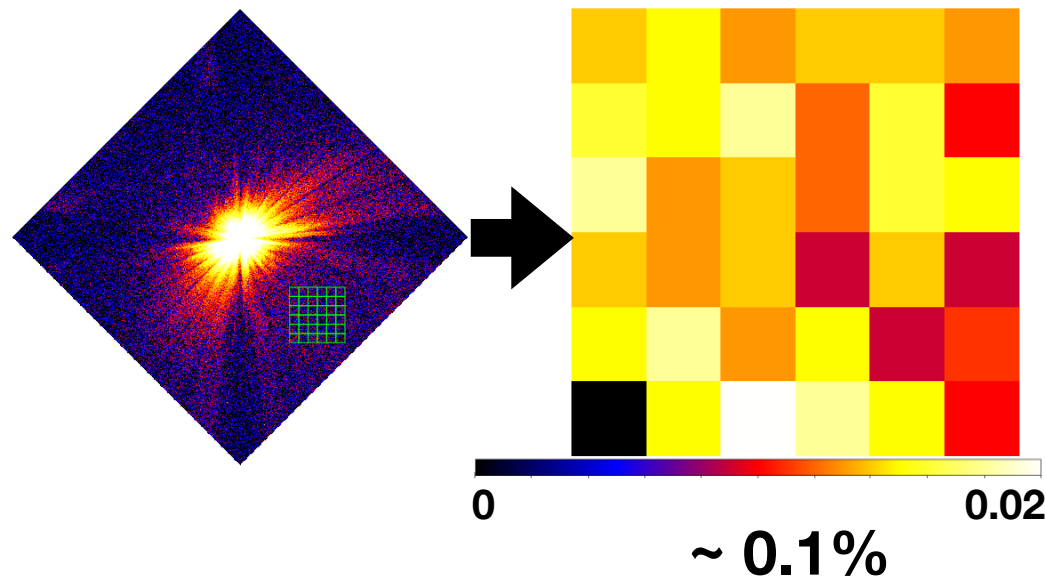
Resolve off-axis PSF (6' & 9')

(Measurement)

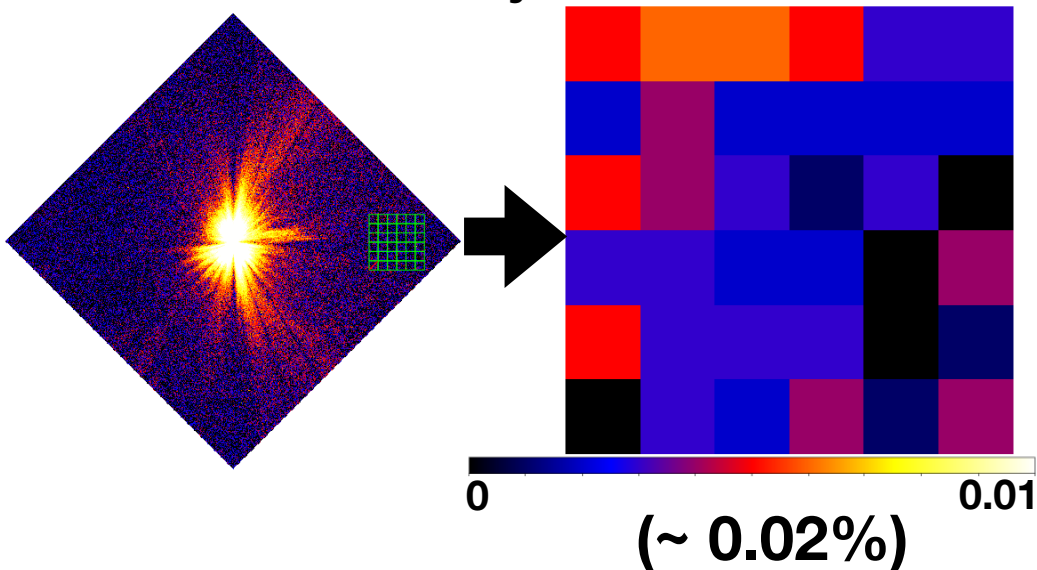
6'-off in QT boundary direction



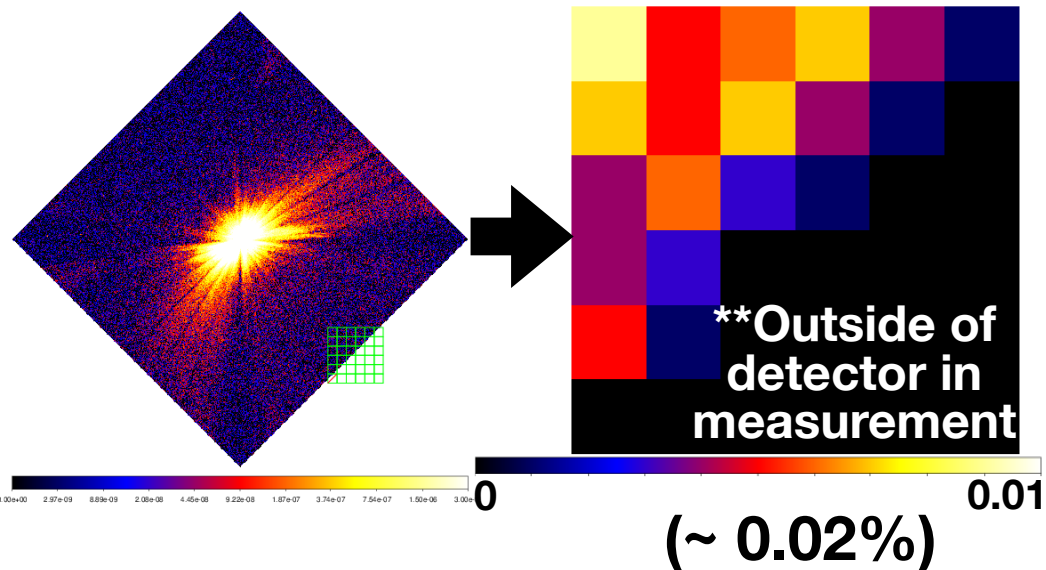
6'-off in QT center direction



9'-off in QT boundary direction

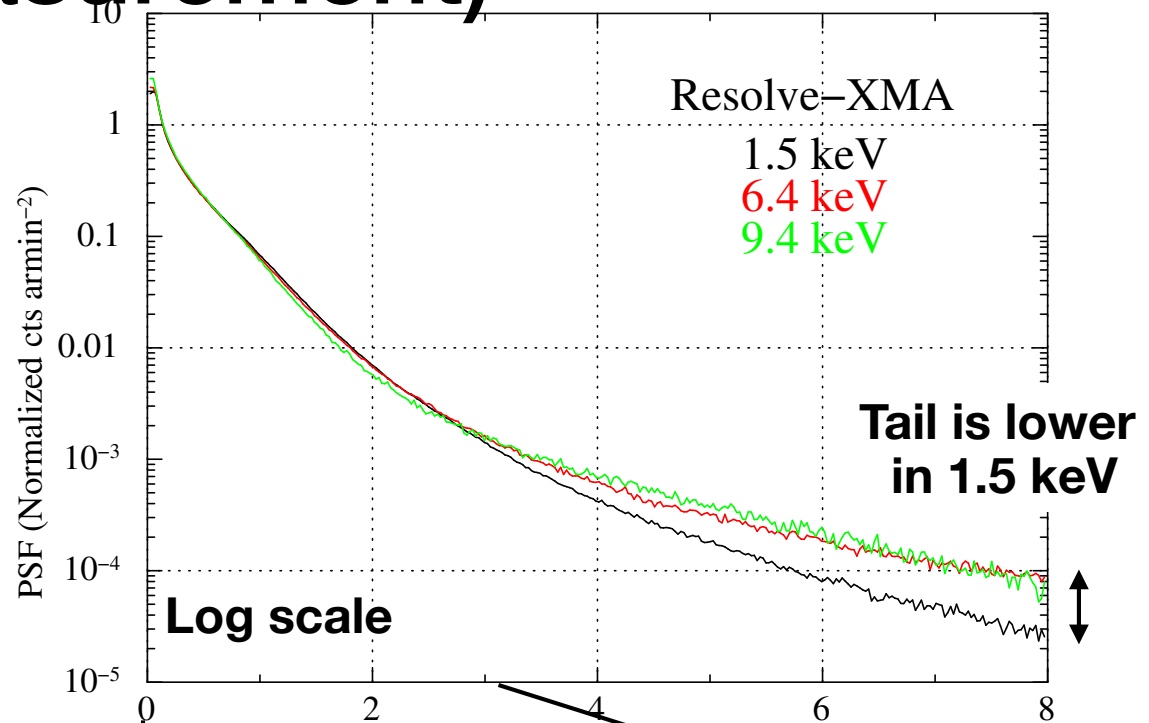
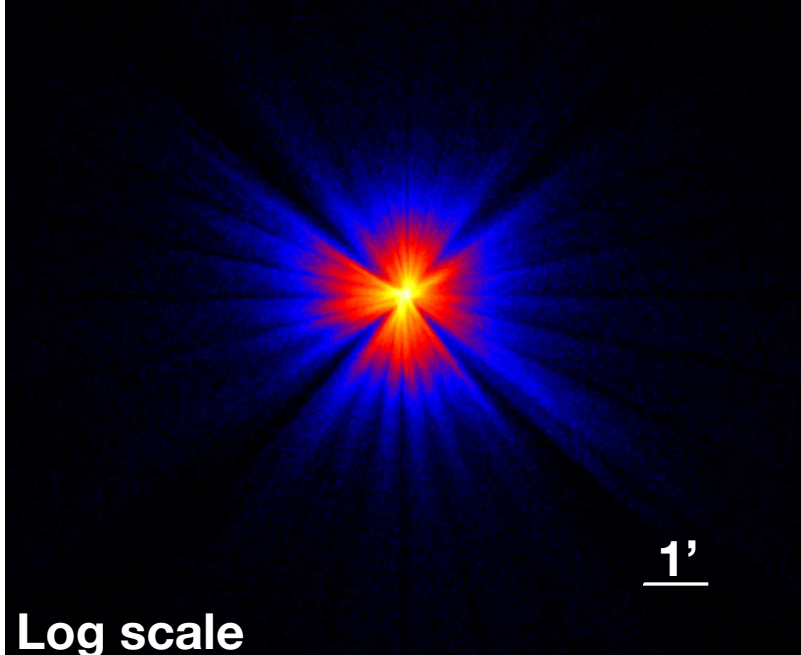


9'-off in QT center direction



On-axis XMA PSF (Measurement)

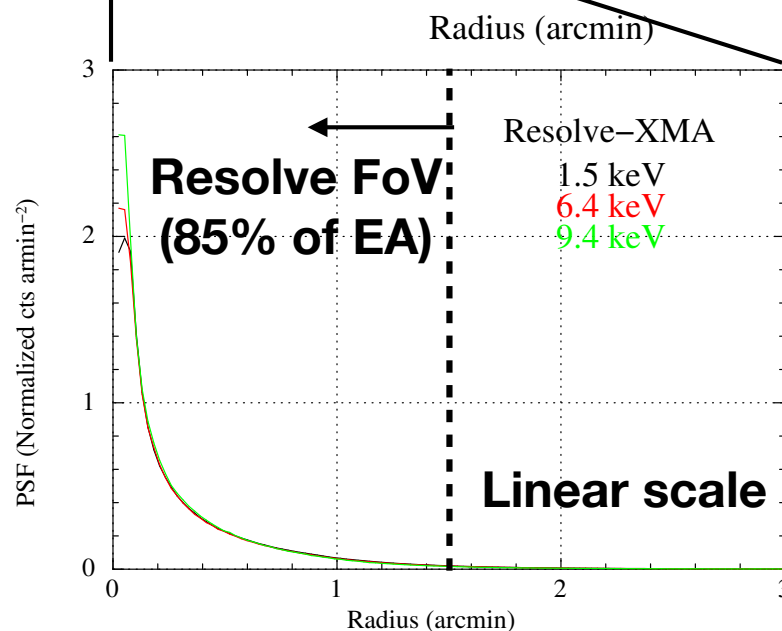
Resolve-XMA@6.4 keV



- HPD@6.4 keV
Resolve-XMA: 1.30'
Xtend-XMA: 1.47'

- FWHM@6.4 keV
Resolve-XMA: 7.9"
Xtend-XMA: 7.2"

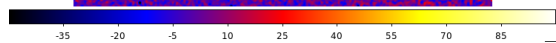
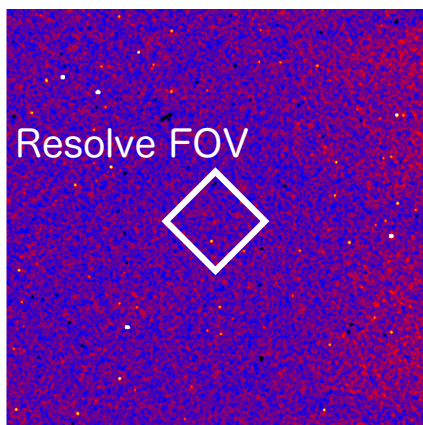
→ Sharp core!



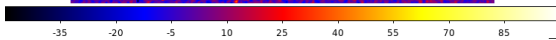
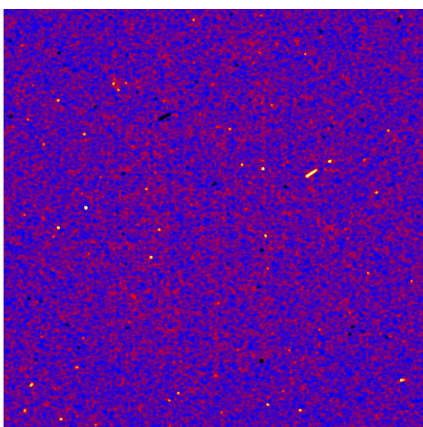
Stray light

Al Ka (1.5keV)

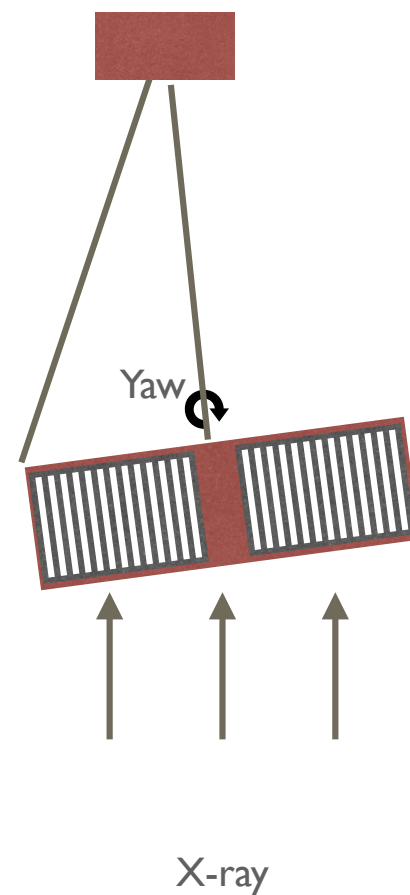
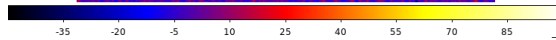
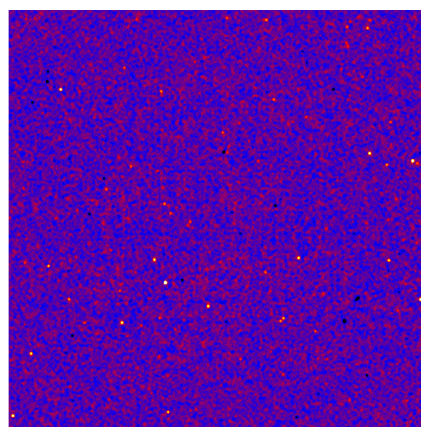
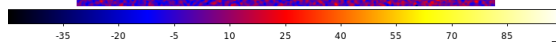
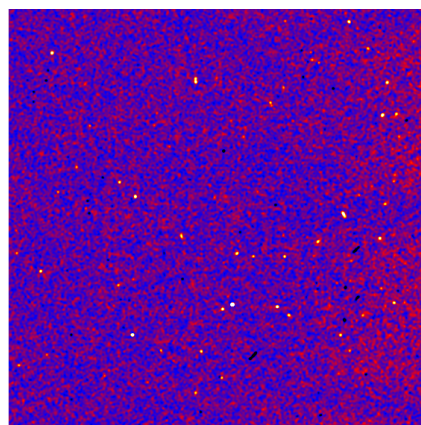
Resolve-XMA



-60' off



Xtend-XMA



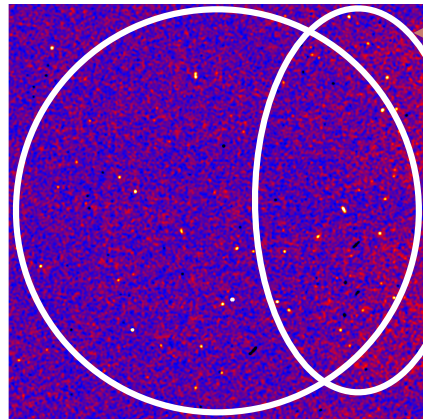
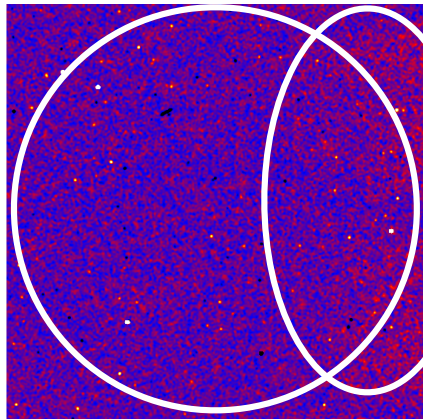
Stray light

Al Ka (1.5keV)

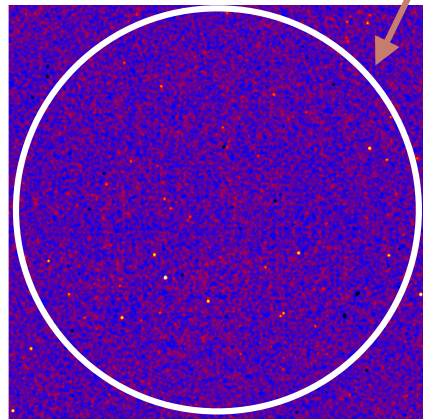
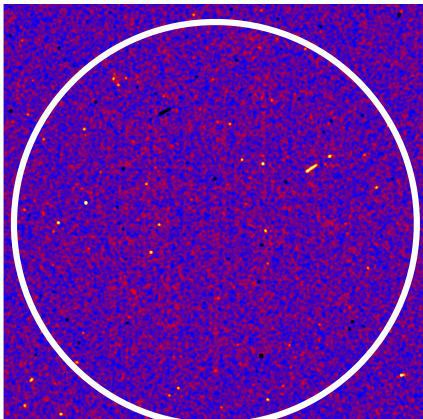
Resolve-XMA

Xtend-XMA

-30' off



-60' off



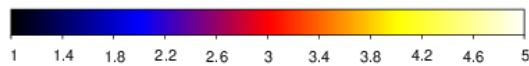
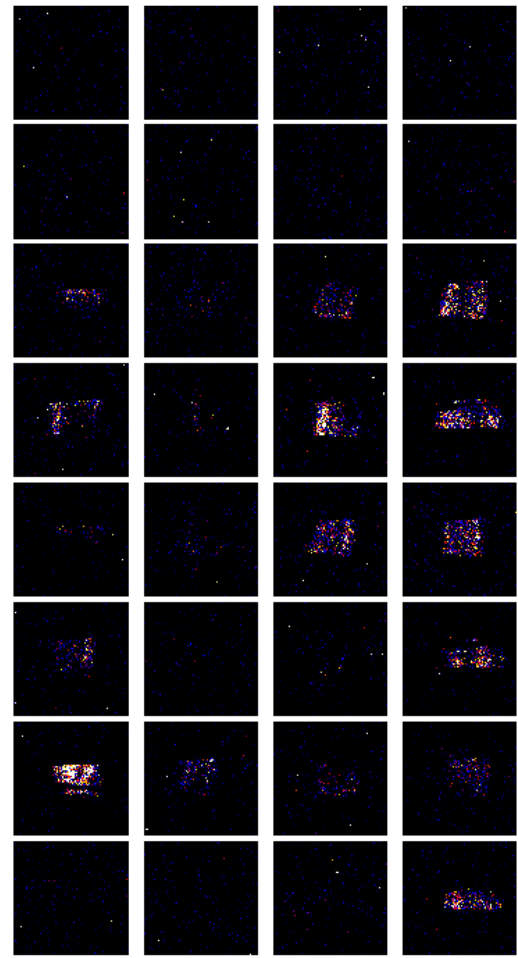
Pre-colimeter
+
Backside reflection

Total amount of Stray light (<8')

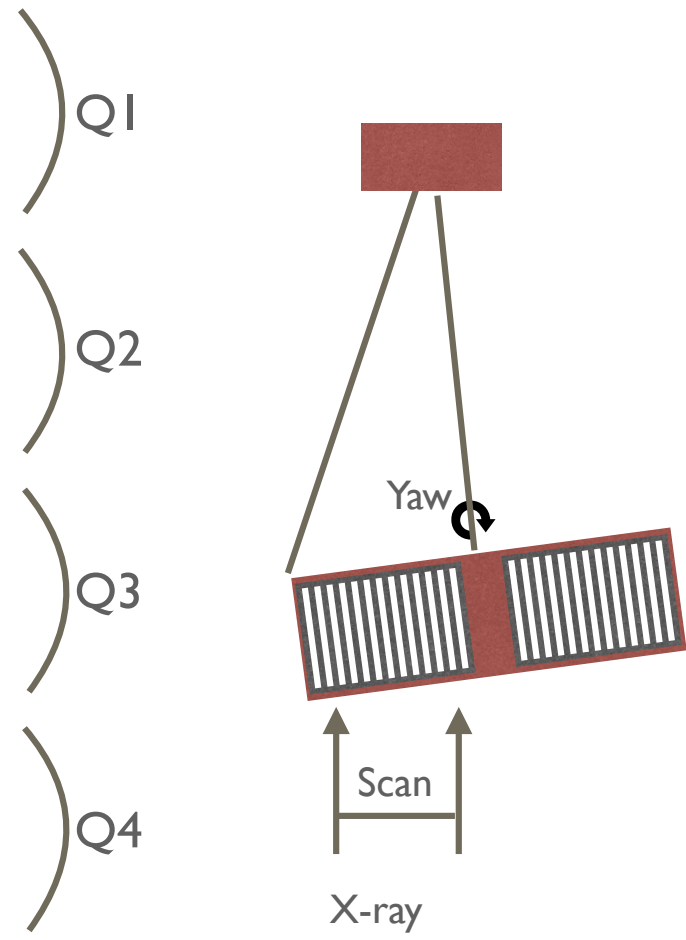
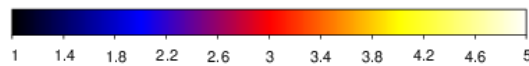
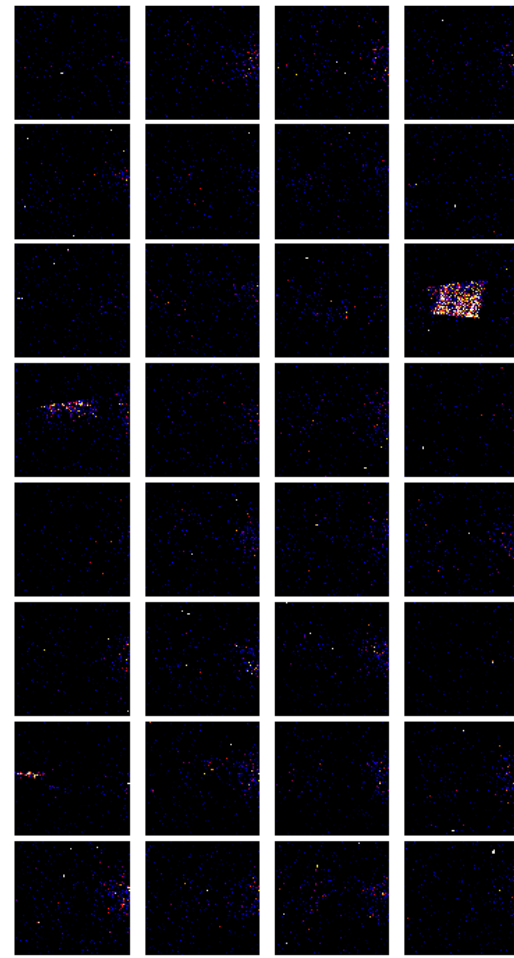
EA [CM2]	RESOLVE-XMA (RESOLVE FOV)	XTEND-XMA
-30'	0.26 (0.003)	0.29
-60'	0.18 (0.009)	0.05

Stray Light from each sectors

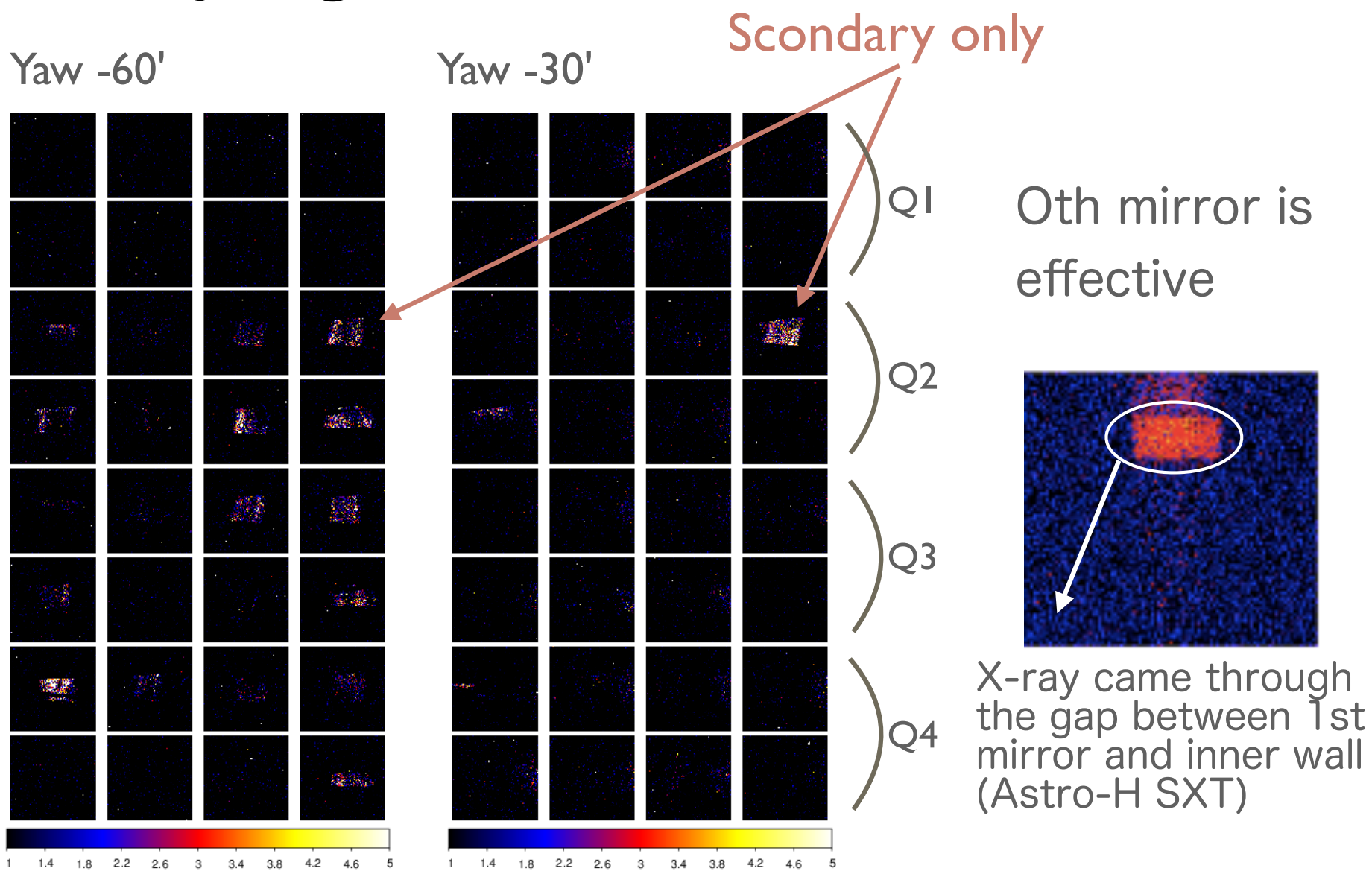
Yaw -60'



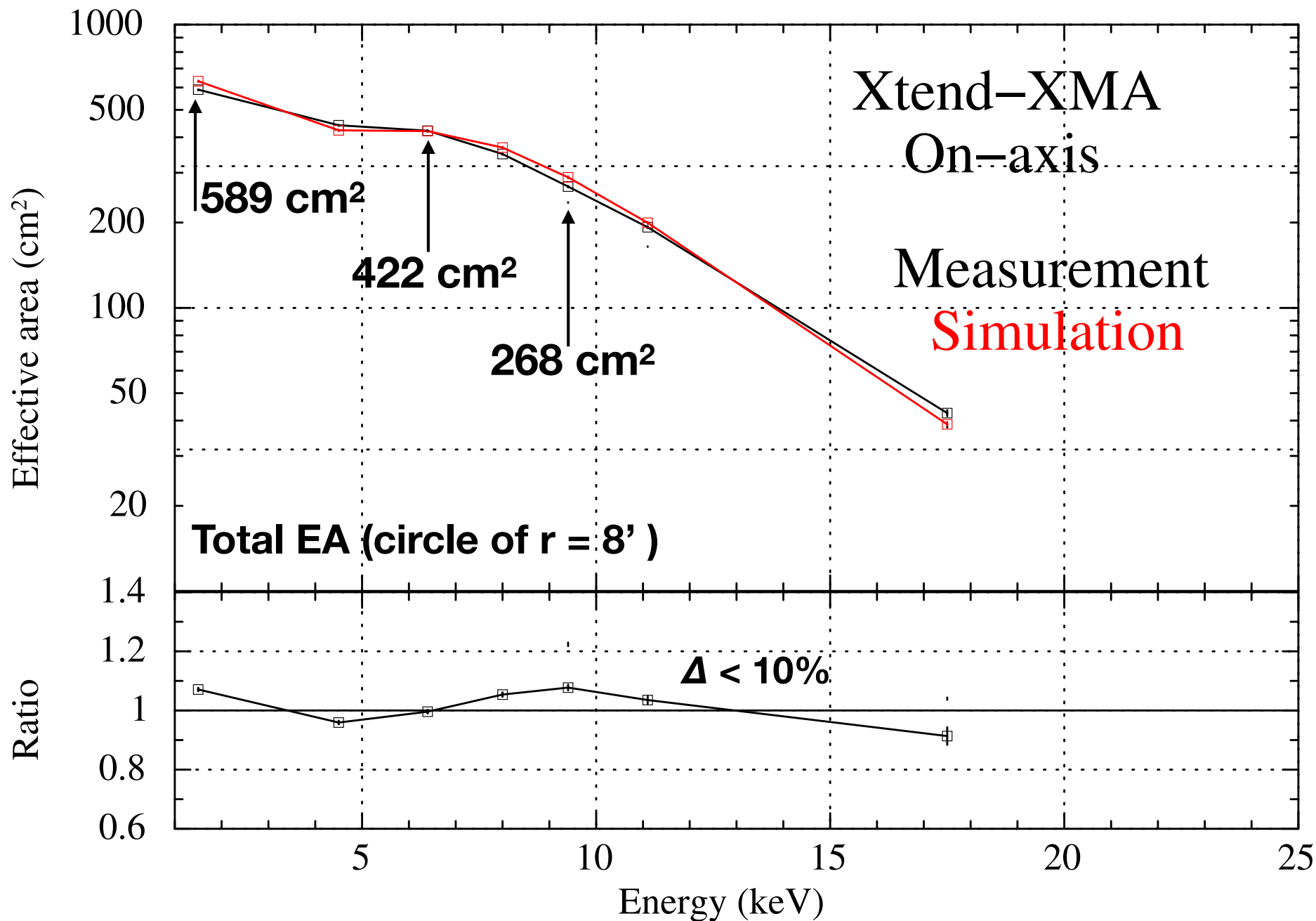
Yaw -30'



Stray light

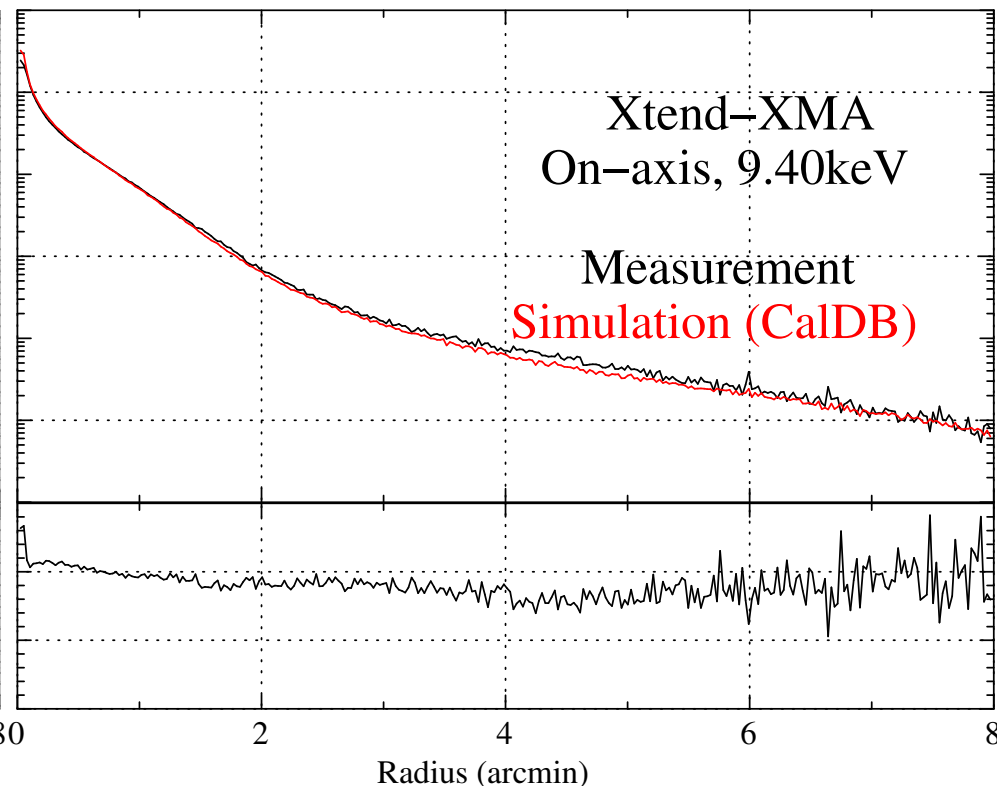
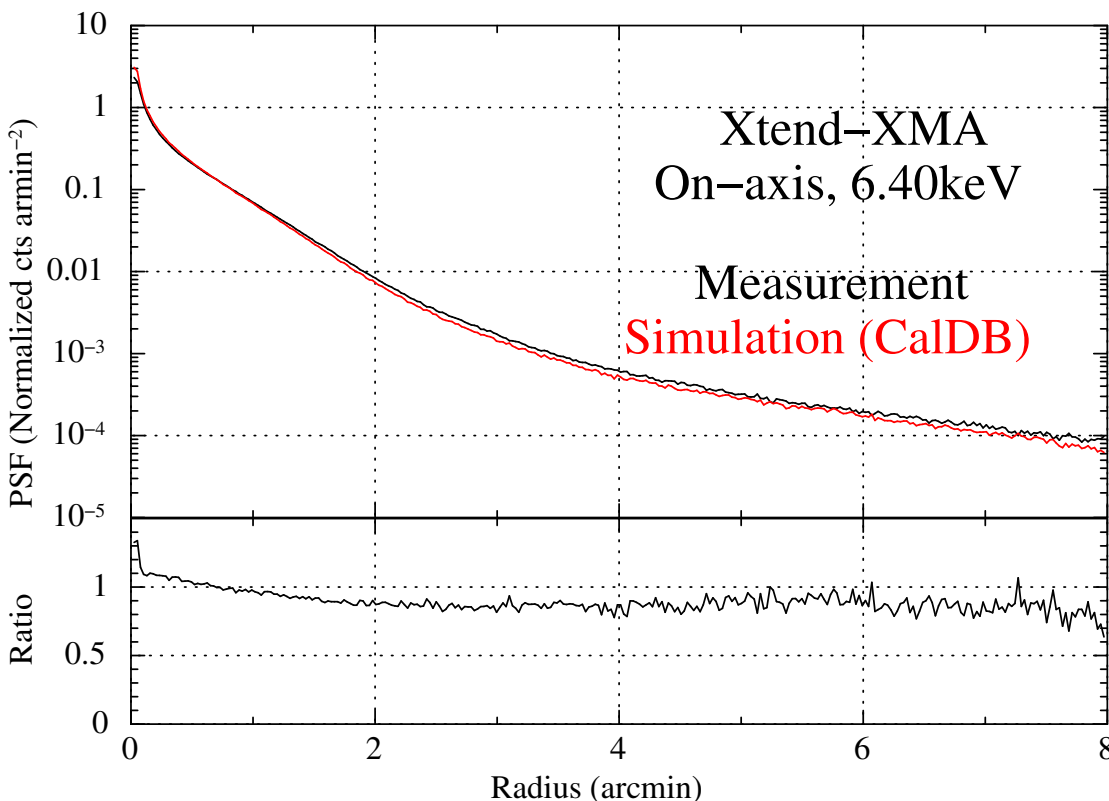
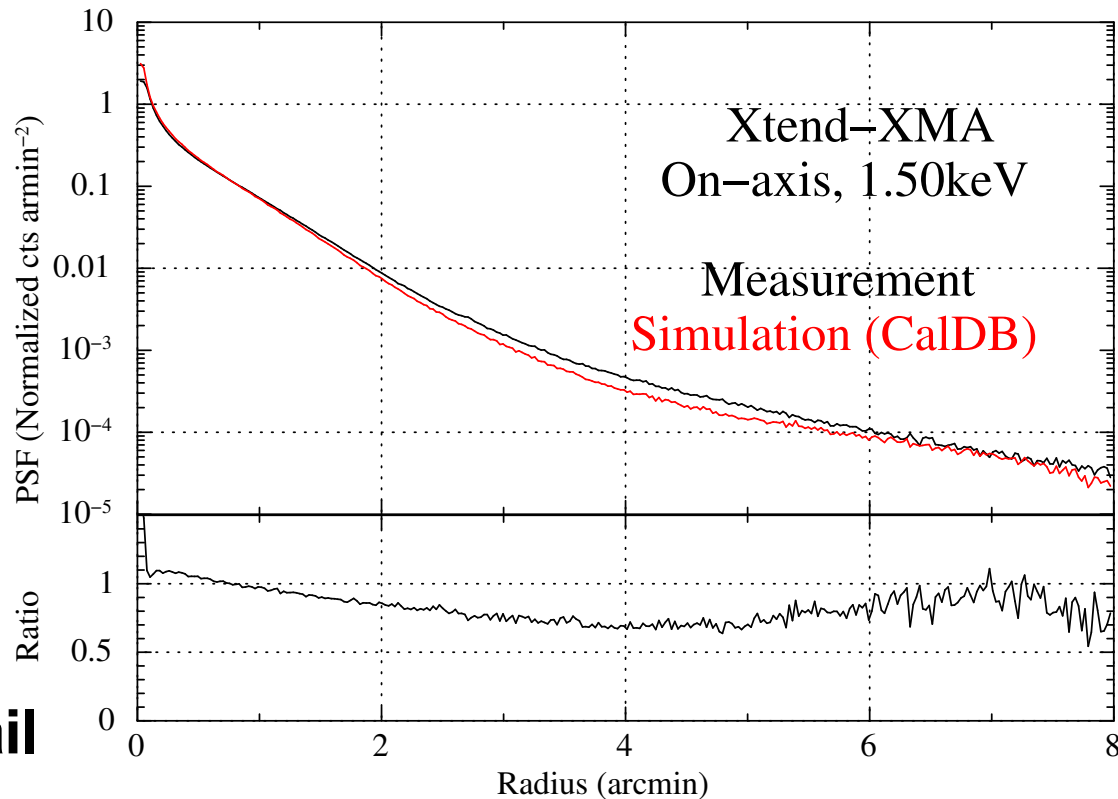


Xtend-XMA on-axis effective area (EA) (Measurement vs simulation)

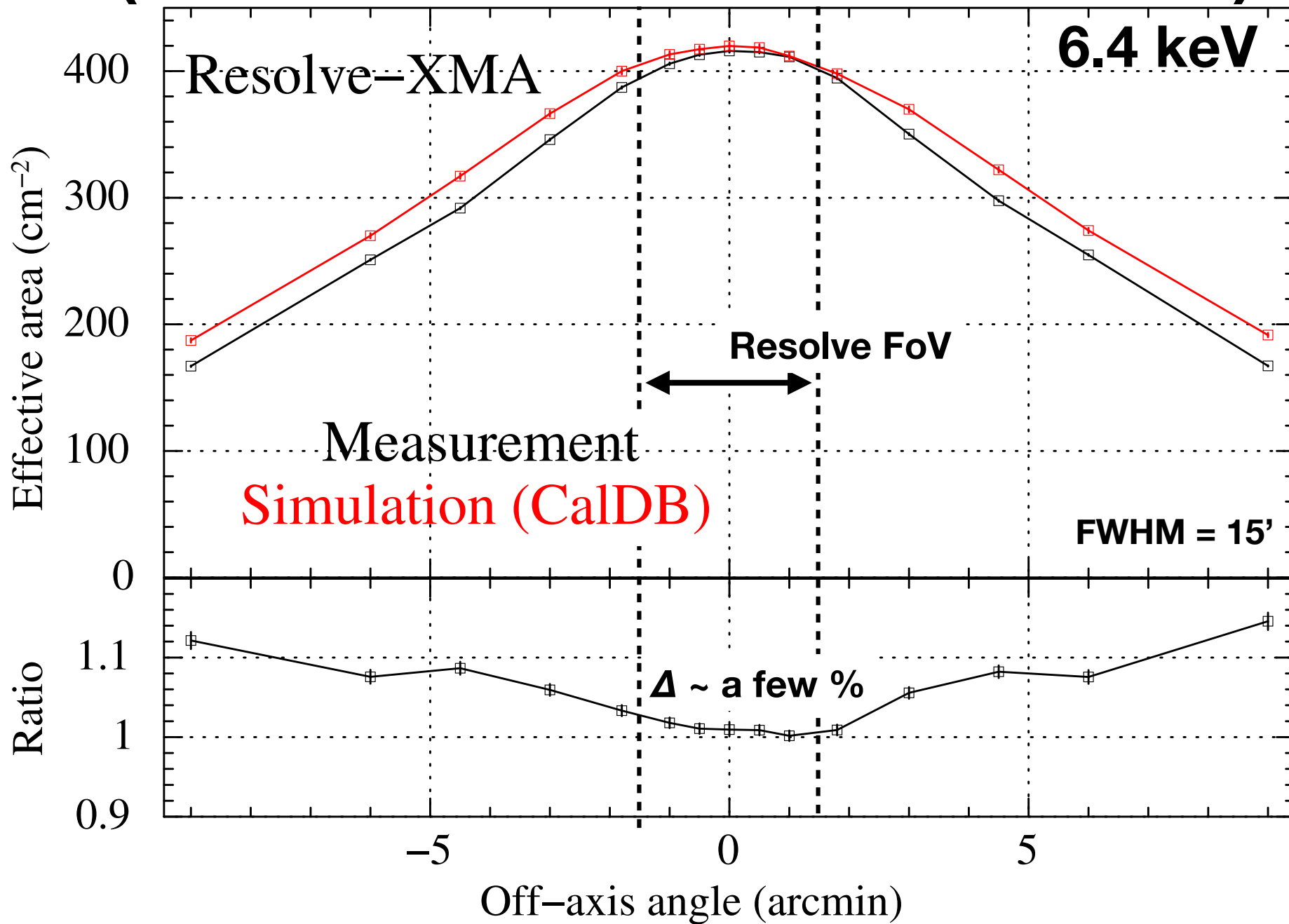


Xtend-XMA on-axis PSF (Measurement vs simulation)

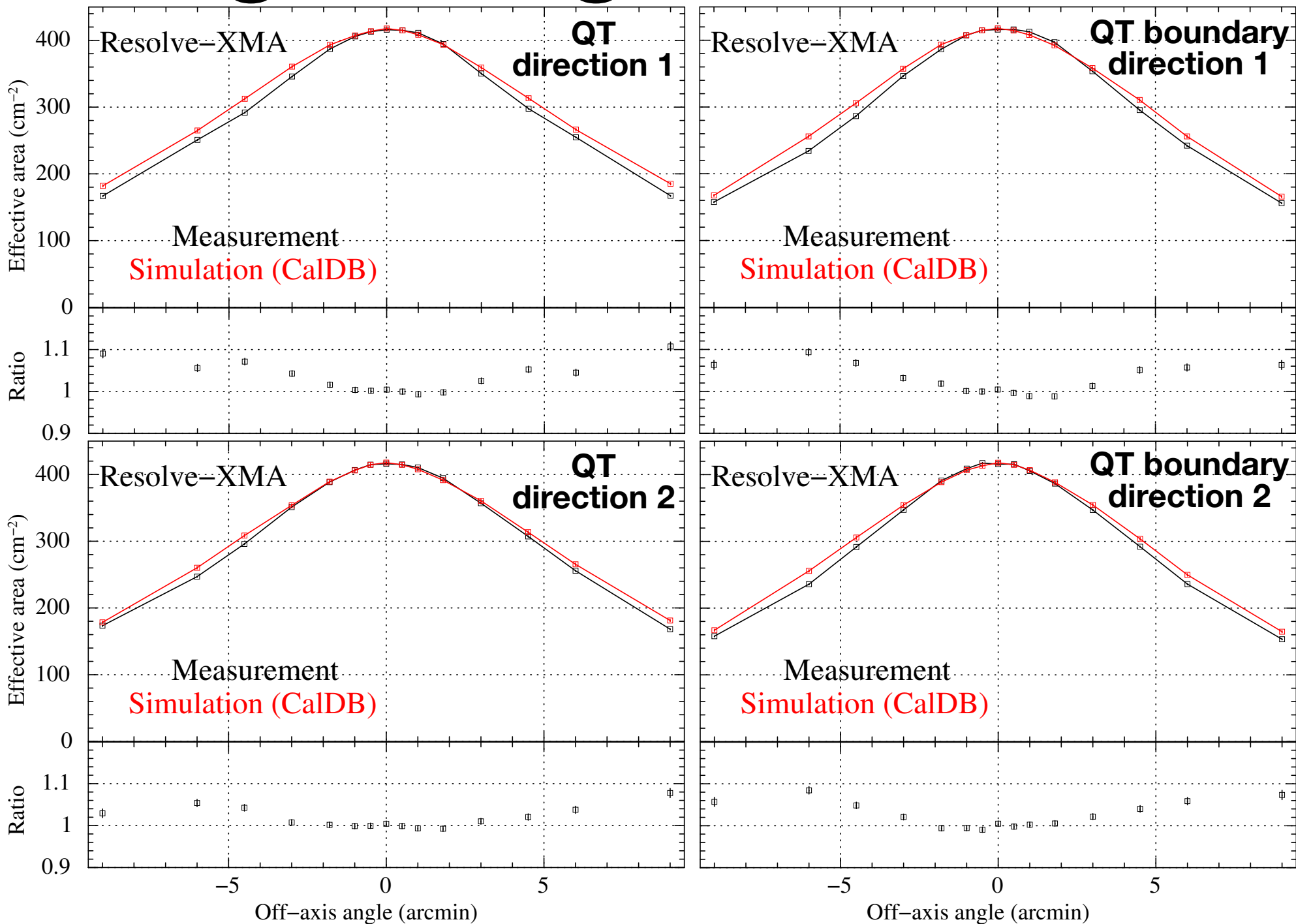
Well modeled including
the energy dependence in the tail



Resolve-XMA vignetting curve (Measurement vs simulation)



Vignetting at 6.4 keV



Vignetting at 6.4 keV

