Physikalisch-Technische Bundesanstalt
Braunschweig and Berlin
National Metrology Institute

Characterization of silicon pore optics for the NewATHENA observatory in the PTB laboratory at BESSY II

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Photon MEADOW 2023

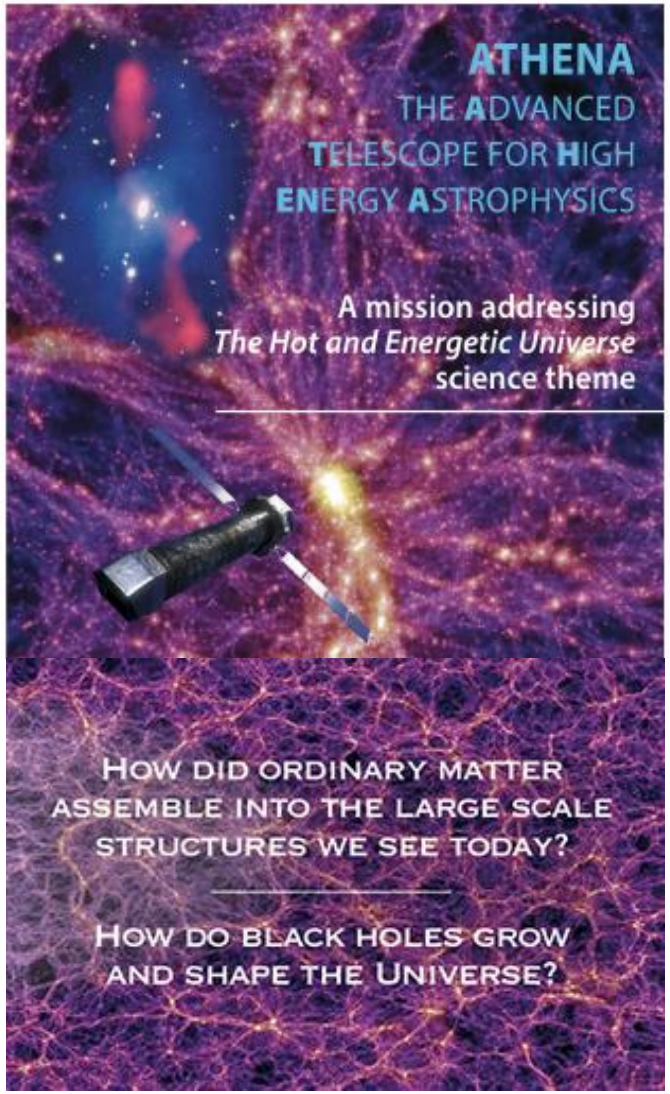
FEL Photon Diagnostics, Instrumentation, and Optics Workshop

MEtrology, Astronomy, Diagnostics and Beamline Design Workshop

Outline

1. The **NewATHENA** observatory
2. The **PTB** laboratory at BESSY II
3. Mirror module assembly and characterization at the **X**-ray **P**arallel **B**eam **F**acility (**XPBF 2.0**)
4. Reflectance measurement on a mirror module at the **F**our **C**rystal **M**onochromator **(FCM)** beamline

NewATHENA facts and figures



- Two instruments (detectors):

  X-ray **I**ntegral **F**ield **U**nit (X-IFU),

  cryogenic imaging spectrometer, 0.3 to 10 keV

  Wide **F**ield **I**mager (WFI),

  silicon active pixel sensor, 0.1 to 12 keV energy range

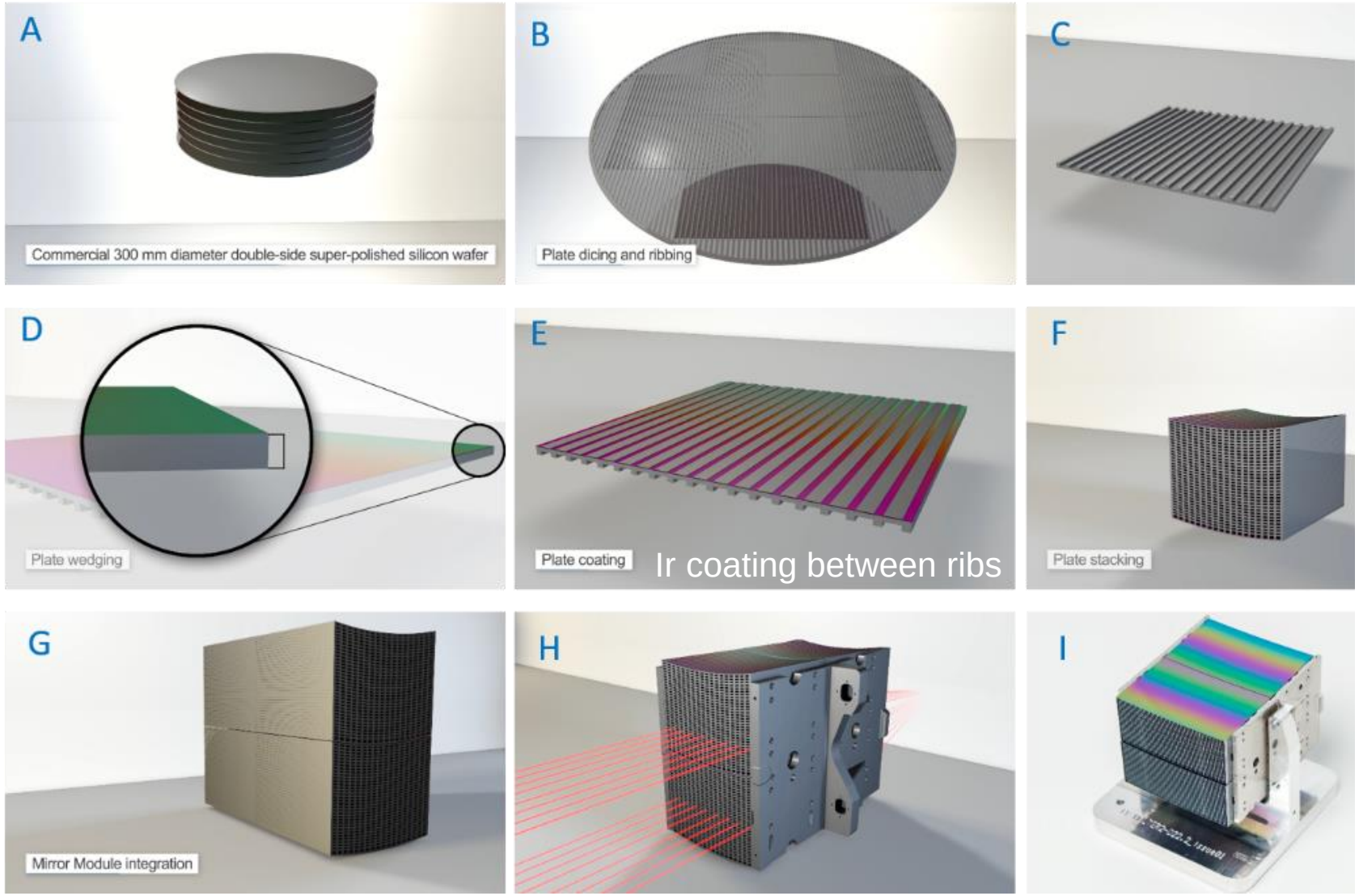
- Effective area of >1.1 m² at 1 keV → mirror surface > 300 m²
- Angular resolution of < 9 arcsec
- Field of view of > 40 arcmin

→ **S**ilicon **P**ore **O**ptics (SPO)

with 12 m focal length

European Space Agency

Silicon Pore Optics (SPO): mirror module production



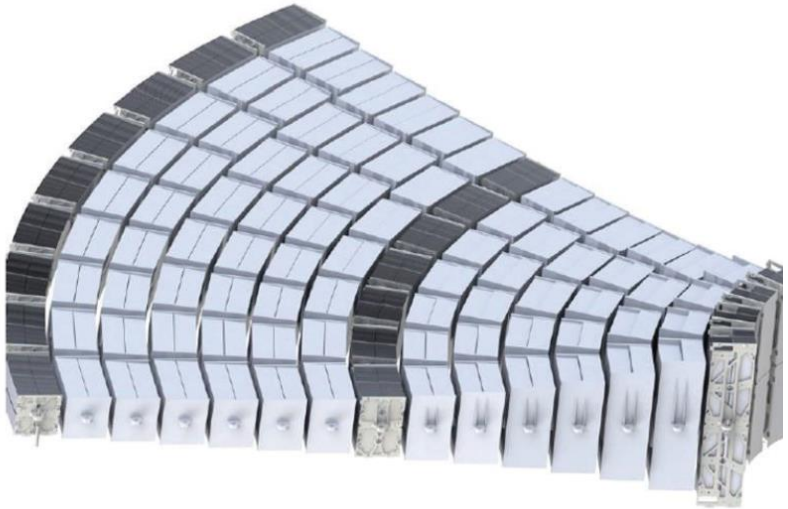
cosine | measurement systems

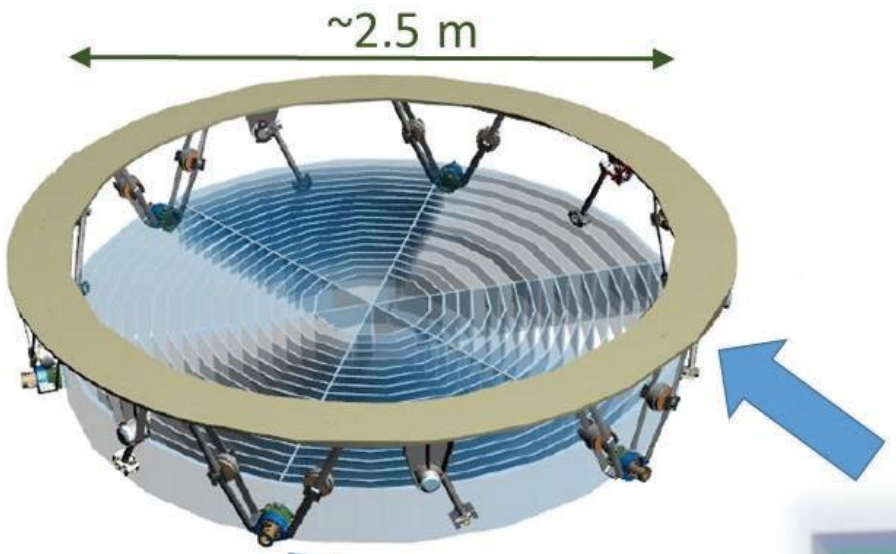
38 plates are assembled to a stack by a stacking robot

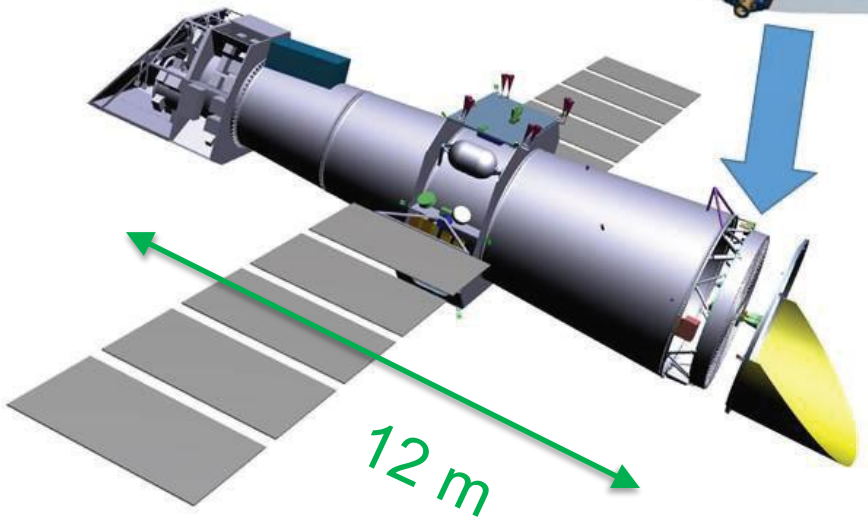
2 stacks are assembled to an XOU (X-ray Optical Unit) for primary and secondary reflection

2 XOUs form a mirror module (MM)

Silicon Pore Optics (SPO): MM integration in the ‚X-ray lens‘

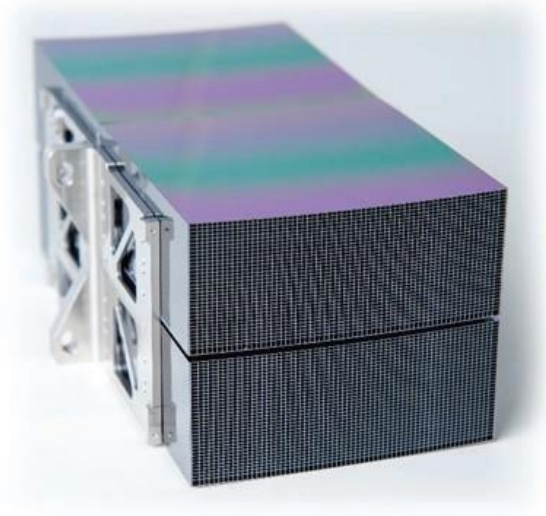






NewATHENA

- 13 rows
- 492 mirror modules



Mirror module (MM)

esa
European Space Agency

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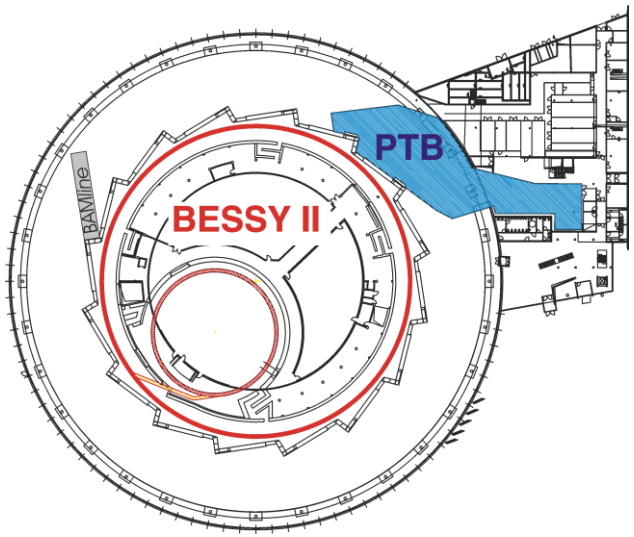
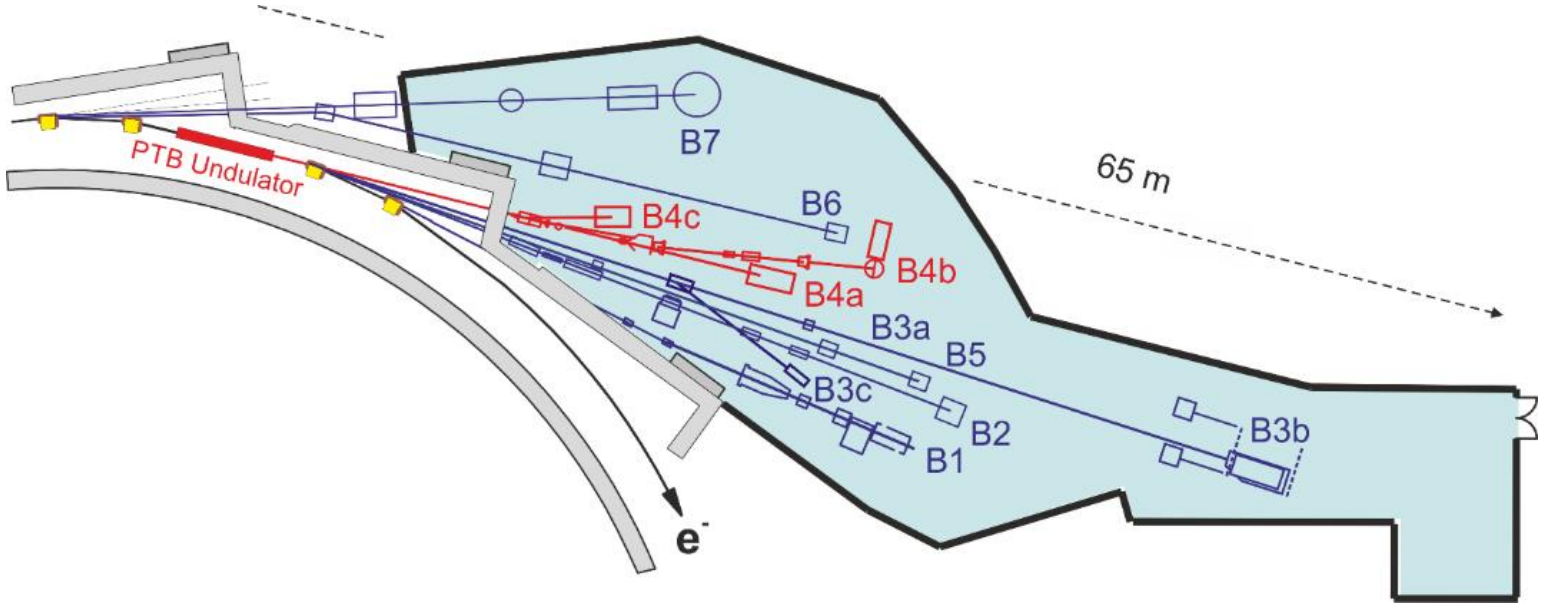
PTB laboratory at BESSY II





Main parameters:

ring circumference	240 m
electron energy	1.7 GeV
max. ring current	300 mA, top-up
beamlines	50

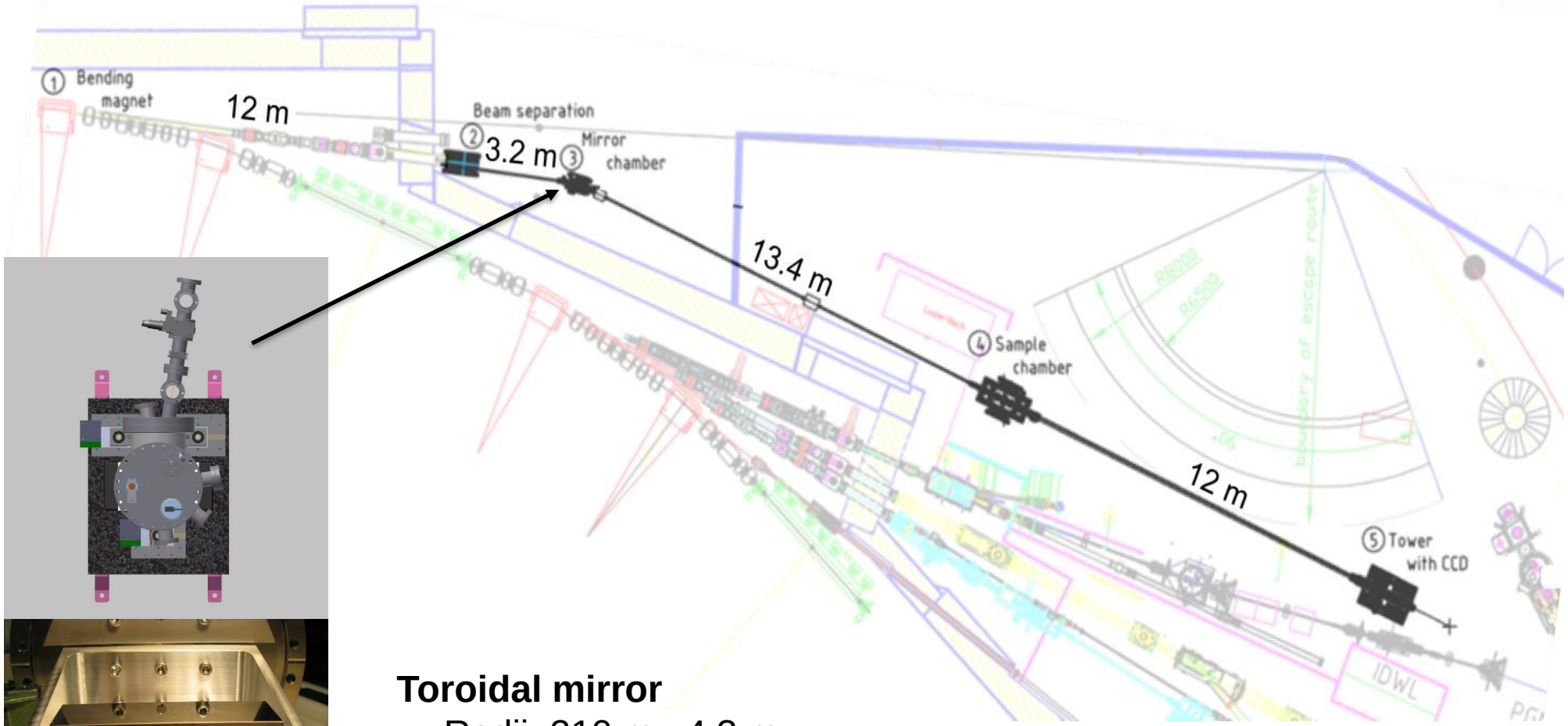
B1	plane grating monochromator SX700 30 eV to 1800 eV	B4b	plane grating monochromator (PGM) at undulator, 40 eV to 1900 eV (30 nm to 0.65 nm)
B2	**four-crystal monochromator (FCM) 1.75 keV to 10 keV (0.7 nm to 0.1 nm)**	B4c	deflected undispersed undulator radiation EUVL metrology test station
B3a	undispersed bending magnet radiation	**B5**	**X-ray pencil beam facility (XPBF), astrophysics optics characterization**
B3b	normal incidence monochromator 3 eV to 35 eV (400 nm to 35 nm)	**B6**	**X-ray parallel beam facility (XPBF 2.0), astrophysics optics characterization**
B3c	deflected undispersed bending magnet radiation, EUV irradiation test station	B7	Tender X-ray microfocus beamline 1.5 keV to 10 keV (multilayer mirror monochromator & DCM)
B4a	undispersed undulator radiation Compton backscattering	B8	BAMline, double multilayer and double crystal monochromator (DCM & DMM), 8 keV to 60 keV

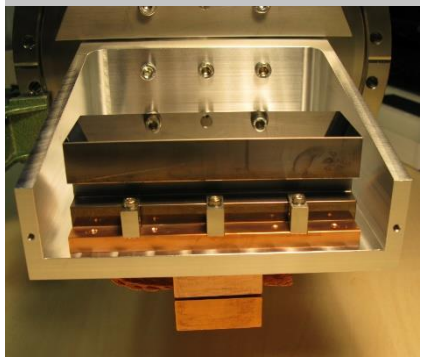
X-ray **P**arallel **B**eam **F**acility (**XPBF 2.0**)

- Cooperation between PTB and ESA for optics and detector characterization with synchrotron radiation since 1994 (BESSY I)
- **X**-ray **P**encil **B**eam **F**acility (XPBF 1) in operation since 2005
- **X**-ray **P**arallel **B**eam **F**acility (**XPBF 2.0**) in operation since 2016, upgraded in 2020

European Space Agency

X-ray Parallel Beam Facility (XPBF 2.0)

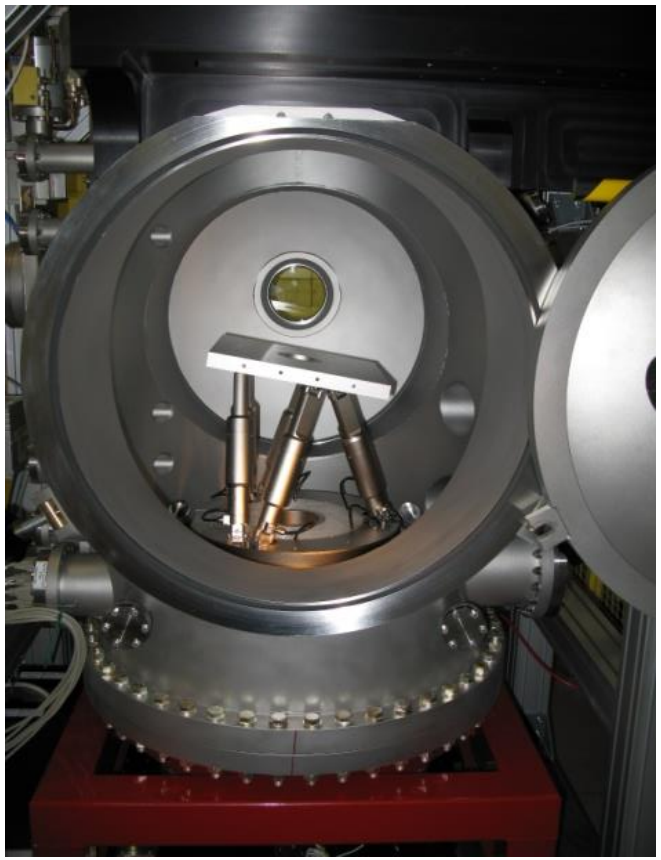


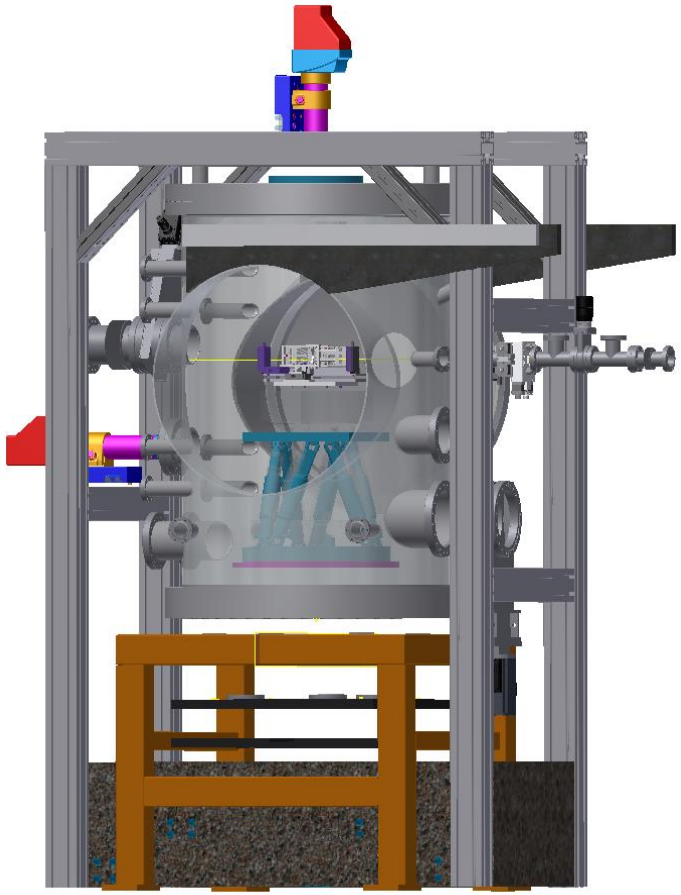


Toroidal mirror

- Radii: 210 m, 4.3 m
- W/Si multilayer coating, *d*-spacing 4.4 nm
- Grazing incidence angle: 8.5°

Sample chamber of XPBF 2.0

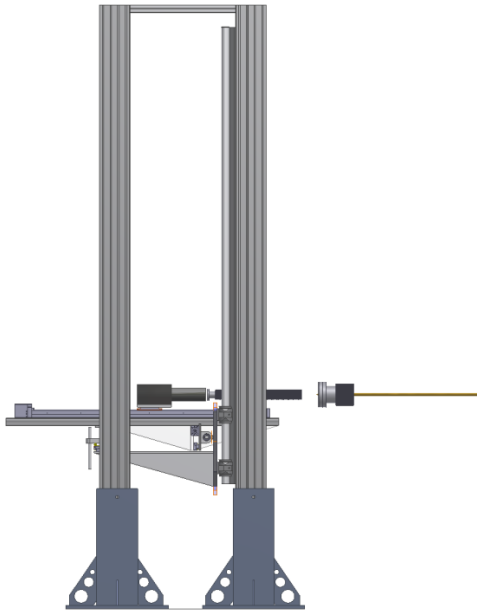


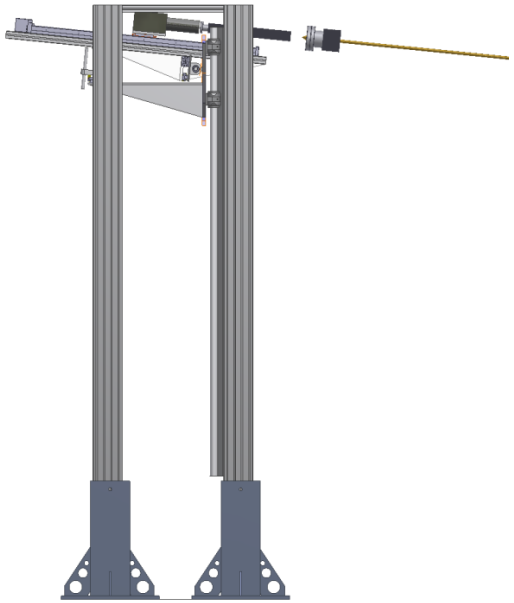


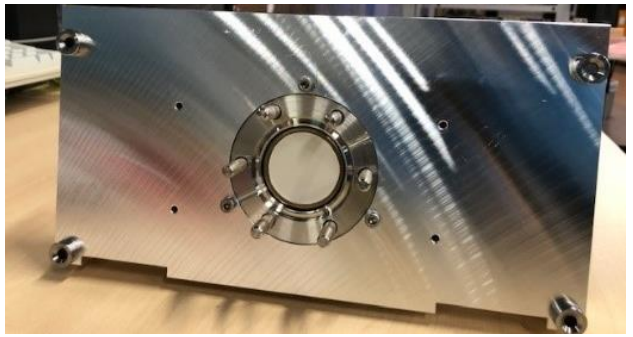
Hexapod for sample (mirror module) positioning

- Travel ranges hor. plane: ± 60 mm, vertical ± 30 mm (+ 85 mm)
- Angular range: 15°, freely selectable pivot point
- Angular positioning accuracy: 0.7 arcsec using feedback from two electronic autocollimators

Detector ‘tower’ of XPBF 2.0



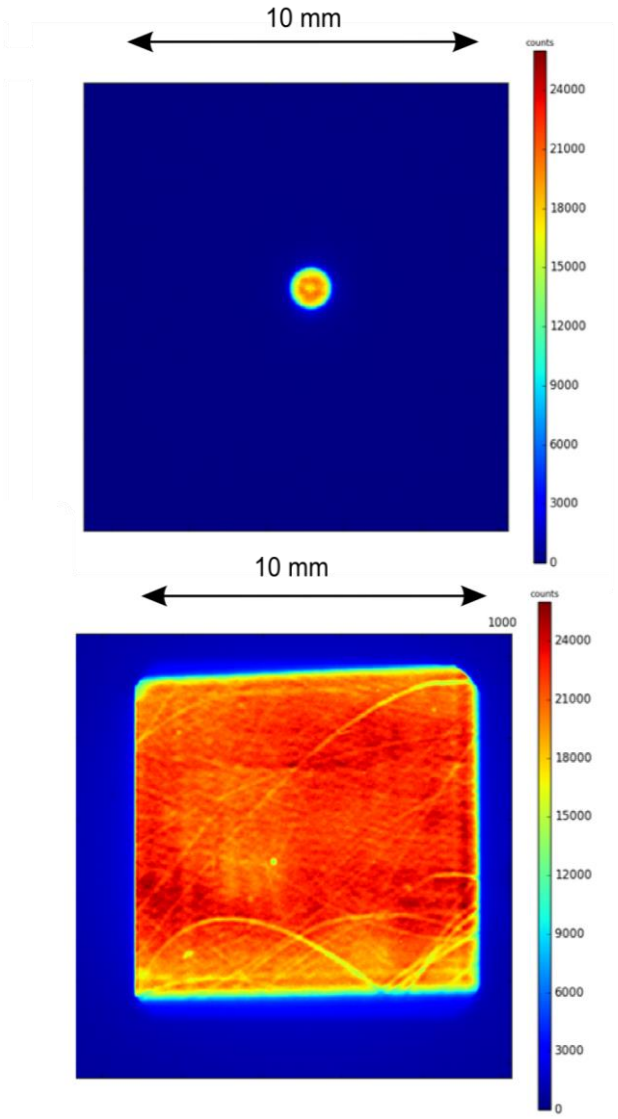




Detector ‘tower’

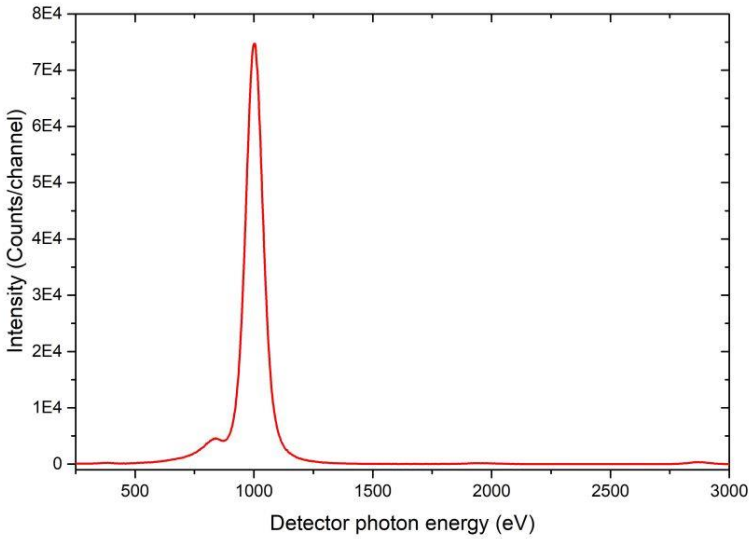
- Vertical translation: 2.1 m
- Translation: in beam direction 1 m, perpendicular 100 mm
- Absolute detector position measurement with laser tracker
- Phosphor screen, tandem optics, CCD camera 2048 x 2048, 13.5 µm pixel size

Available beam at XPBF 2.0



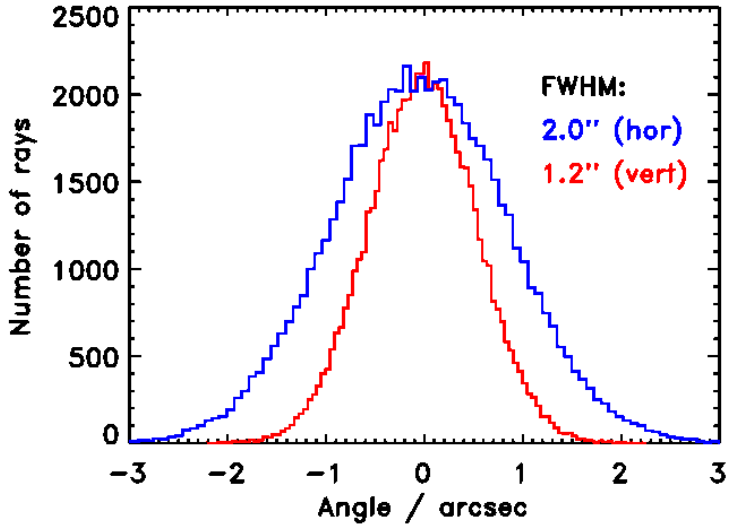
Pinhole beam or large area (typ. 100 µm to 7.5 mm)

Monochromatic, 1 keV



Spectrum measured with SDD

Parallel beam, divergence below 2 arcsec



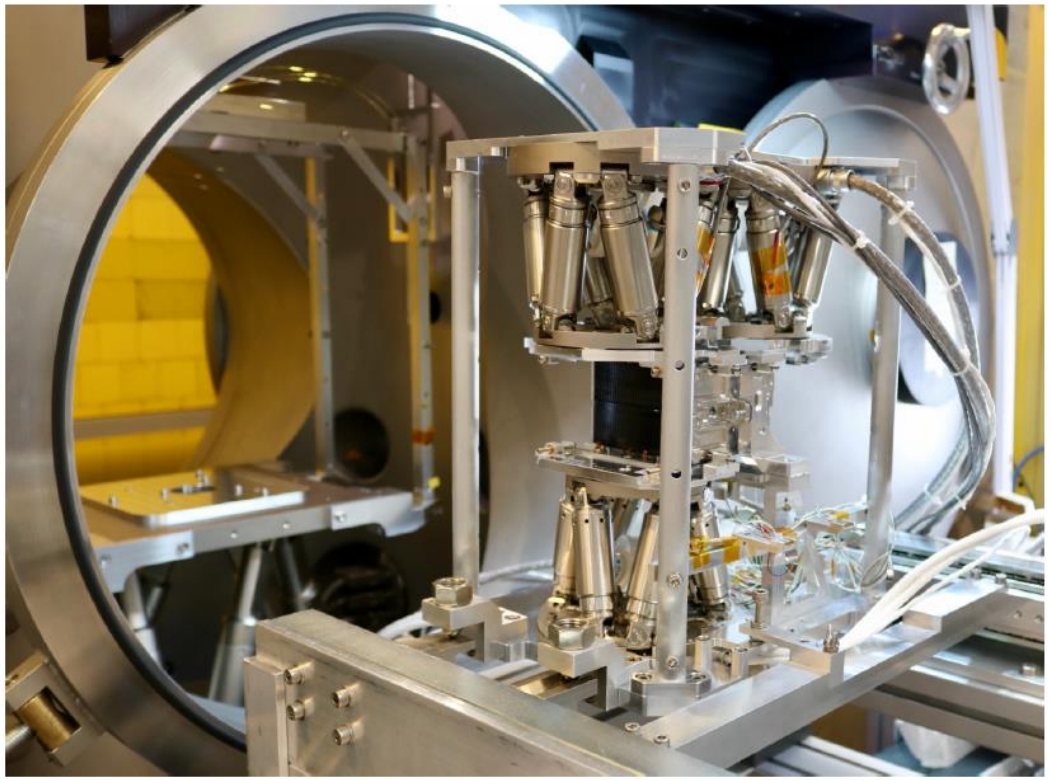
Raytracing result (RAY)

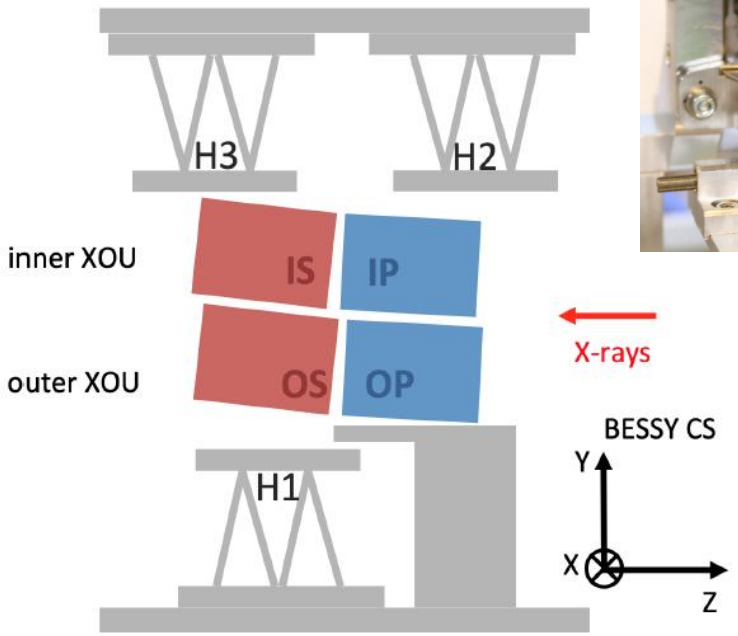
Assembly of mirror modules at XPBF 2.0

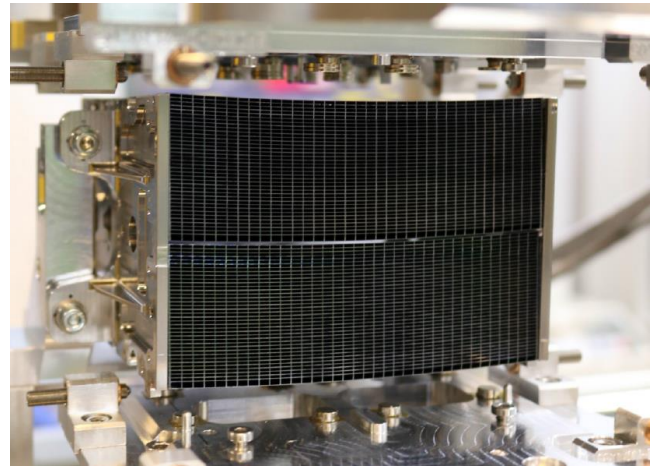
Mirror **M**odule (**MM**): combination of two XOUs

cosine | measurement systems

- Assembled at XPBF 2.0 using 3 hexapods for positioning of the stacks
- X-rays are used for the alignment

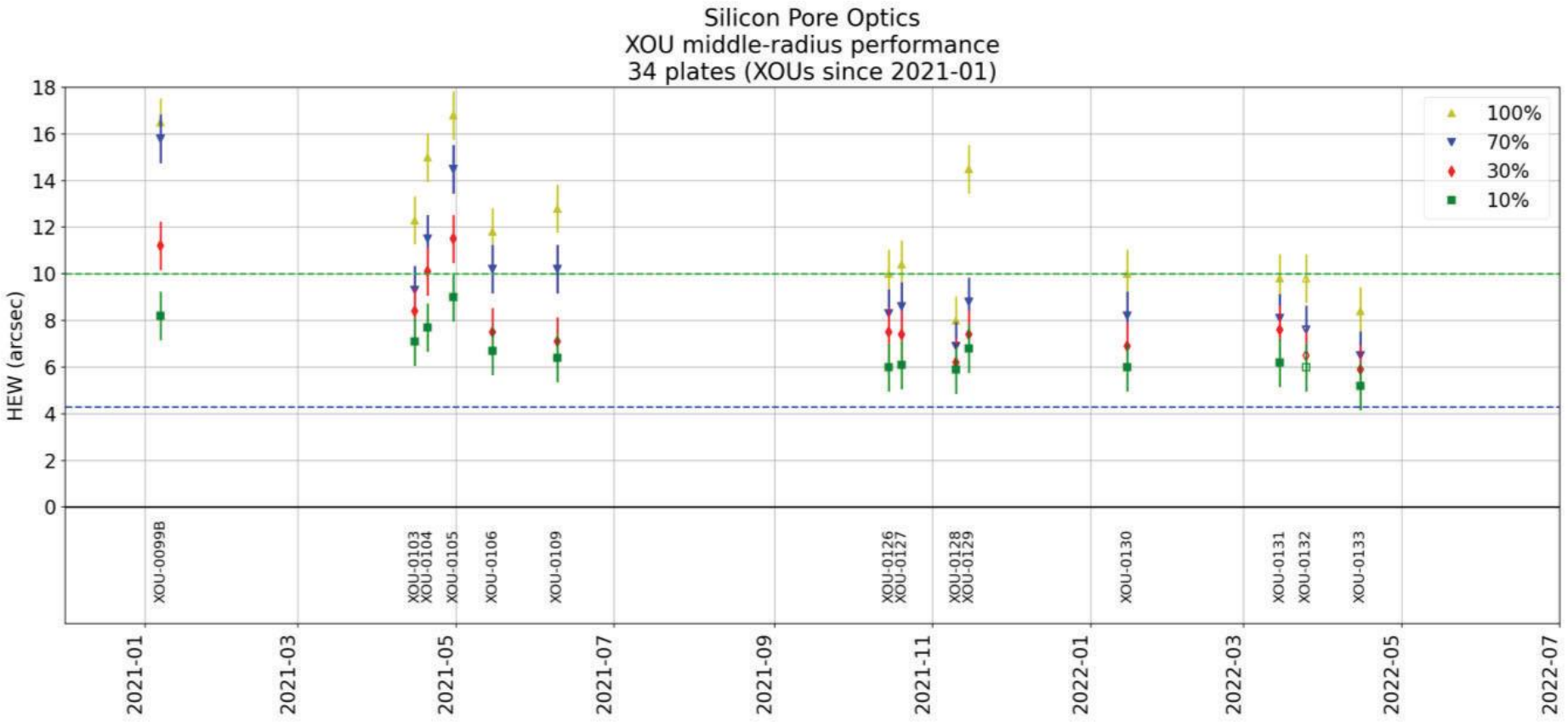


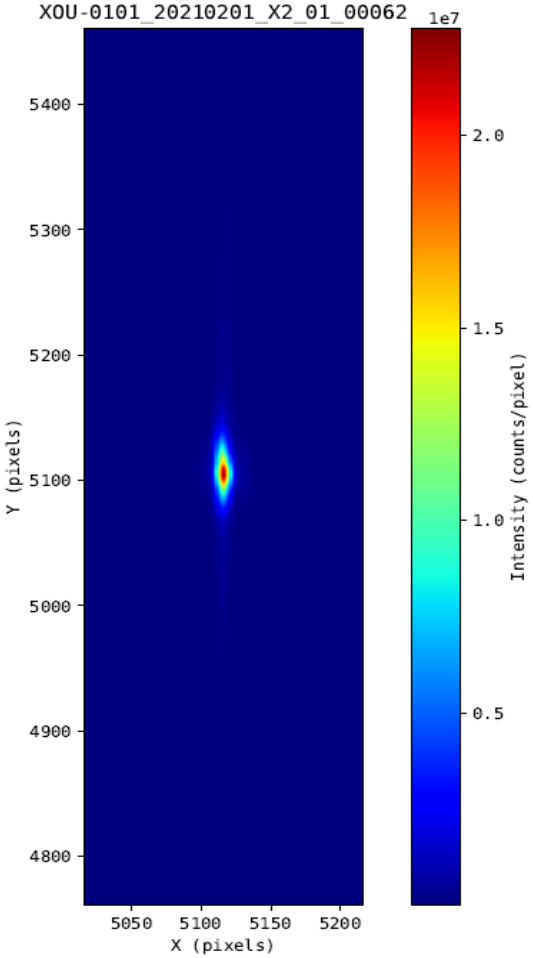




Characterization of XOUs at XPBF 2.0

Time evolution of **X**-ray **O**ptical **U**nit quality





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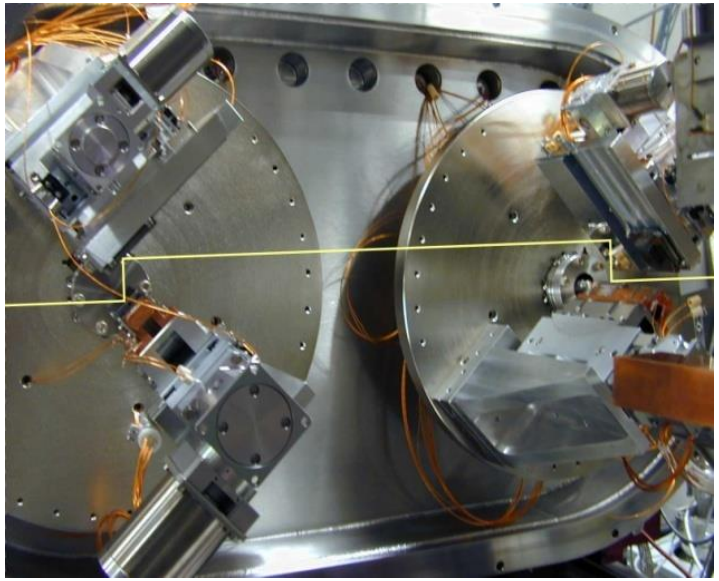
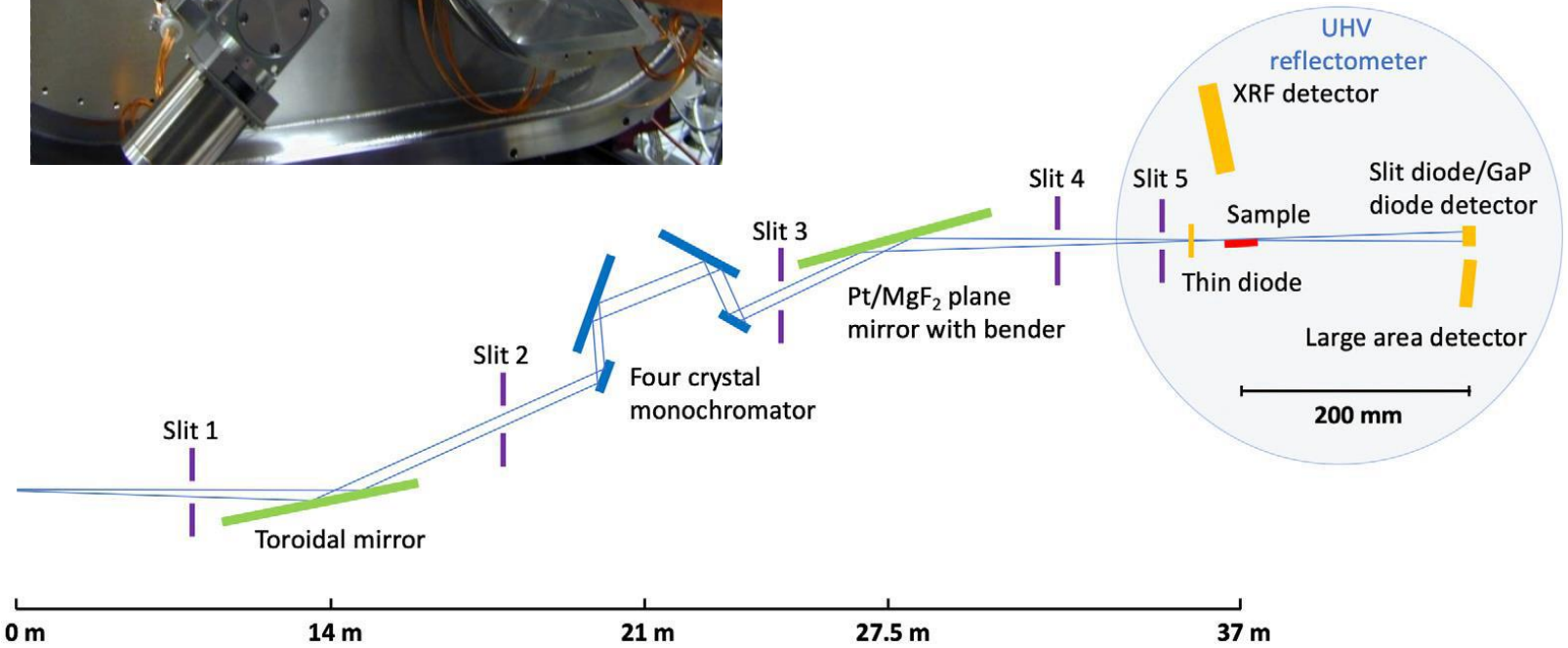
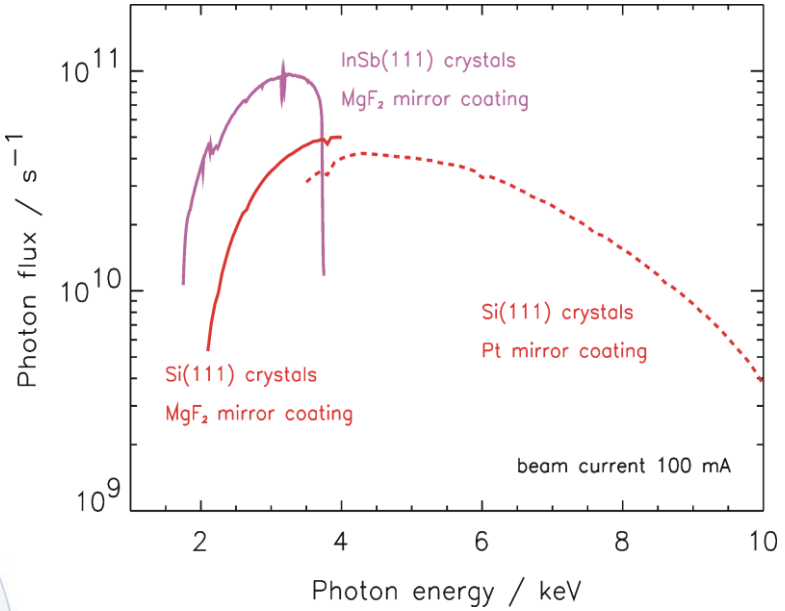
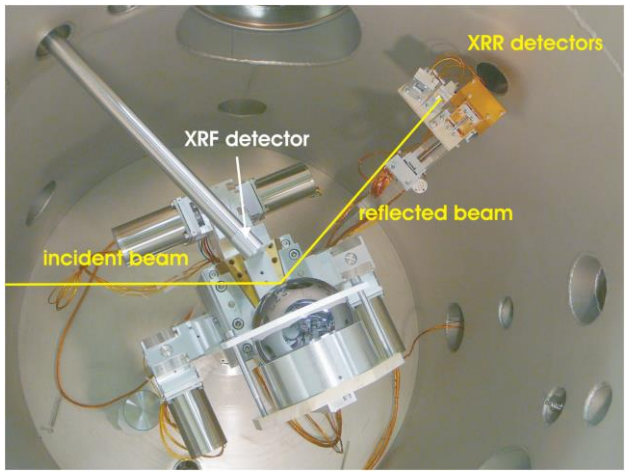
Four Crystal Monochromator (FCM) beamline

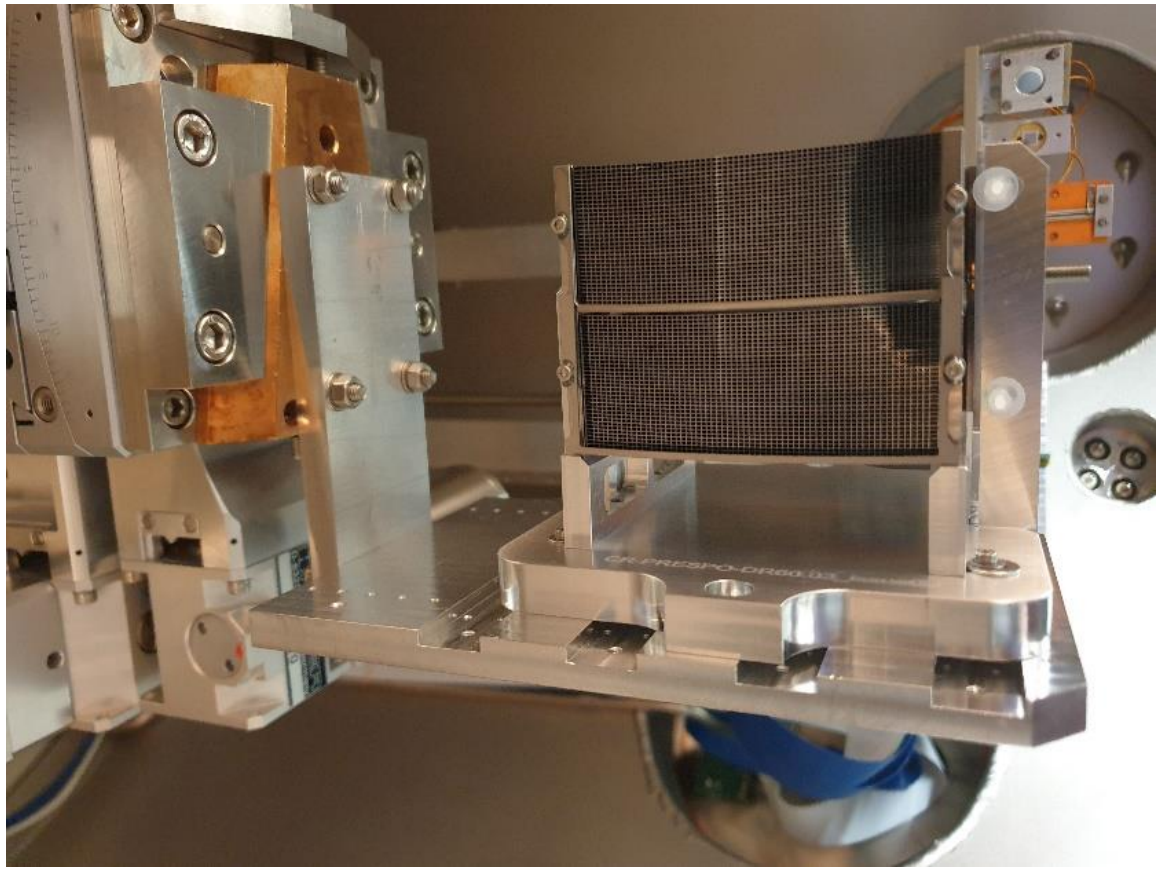


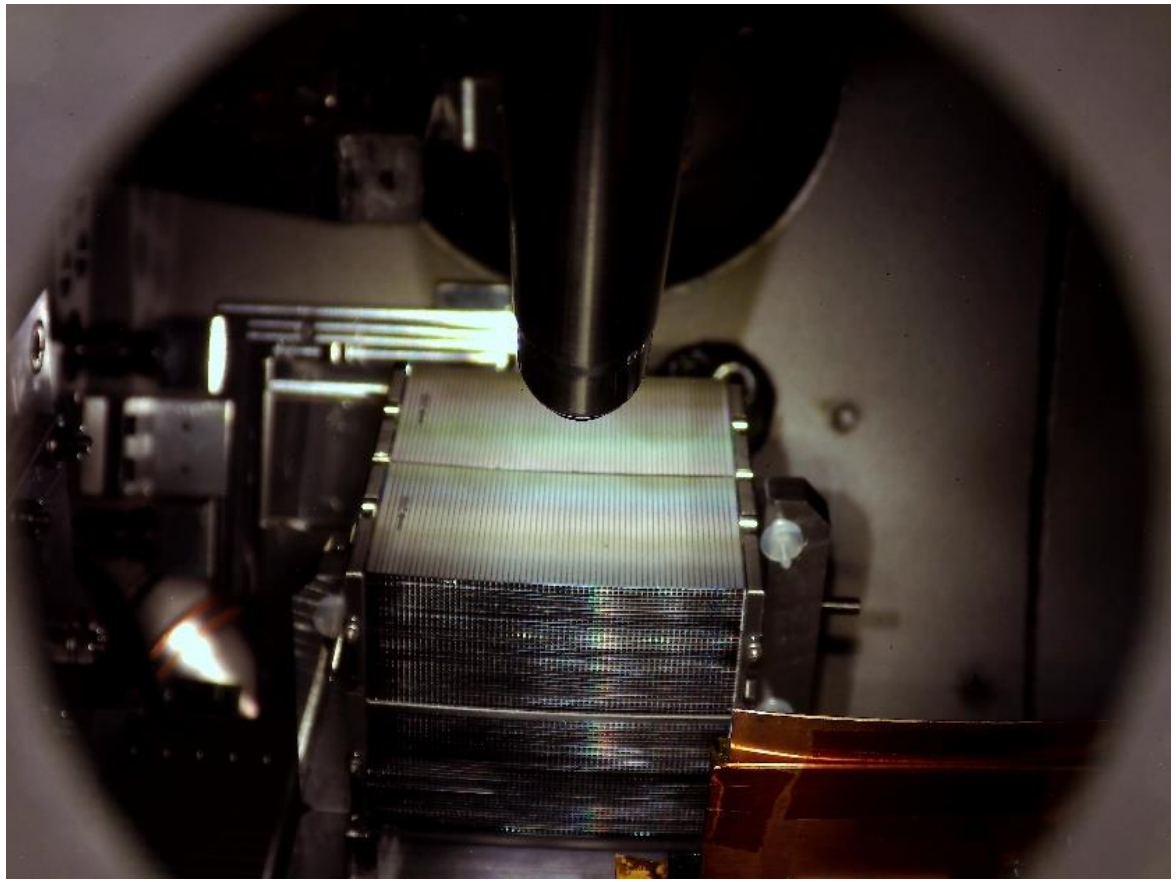




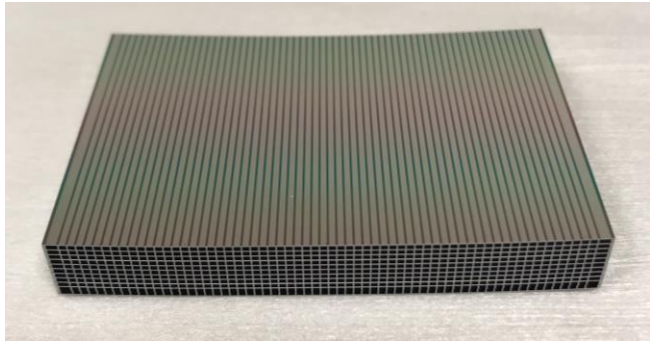


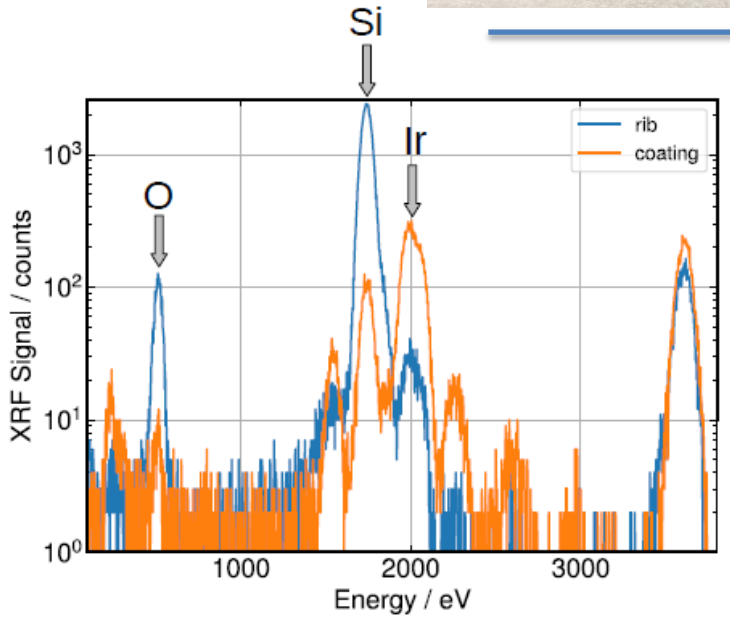
MM-0061 in the reflectometer at the FCM beamline



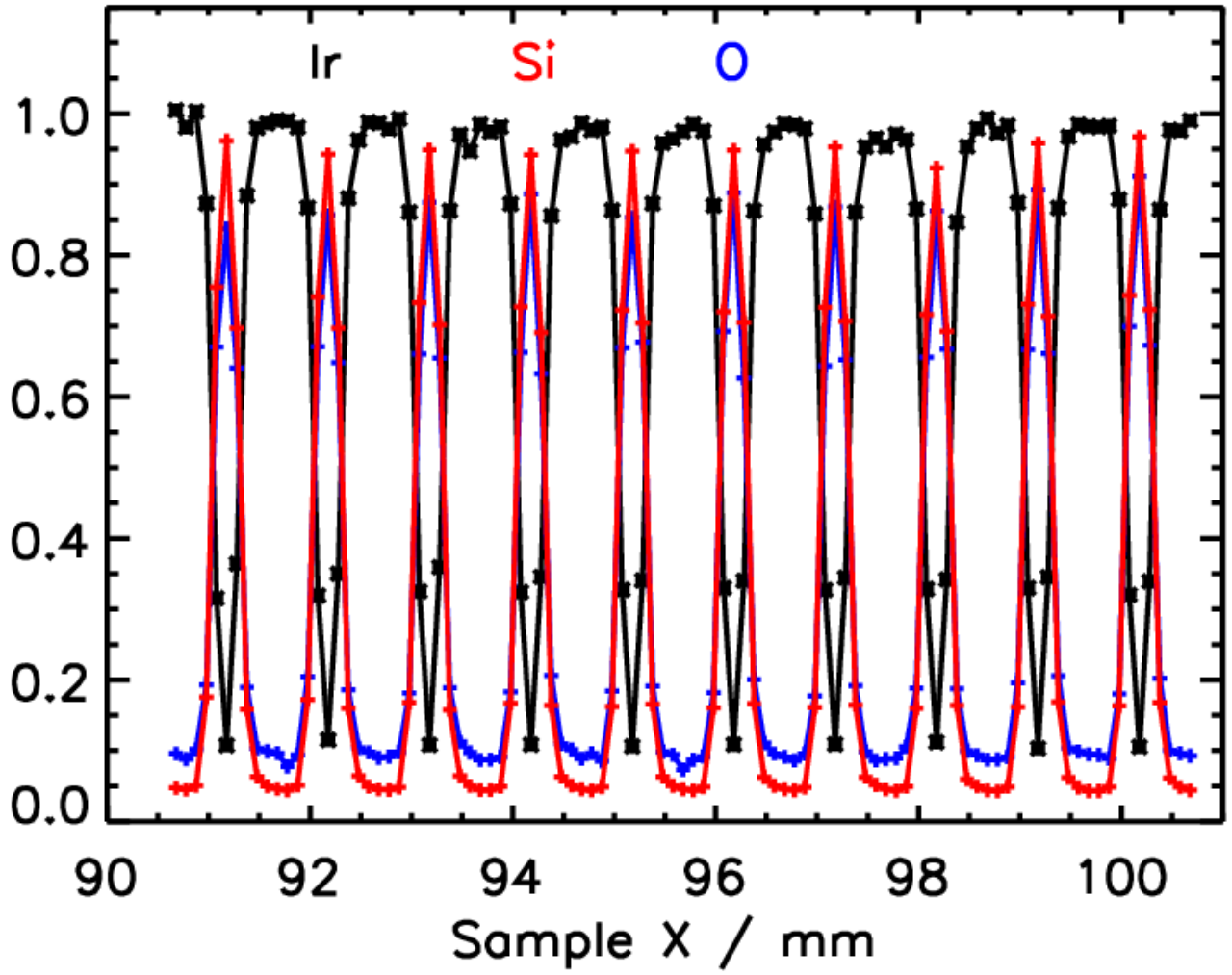


X-ray fluorescence (XRF) scan on part of MM top layer

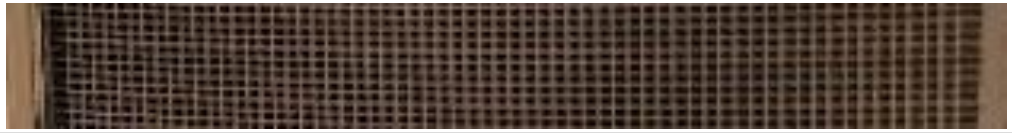


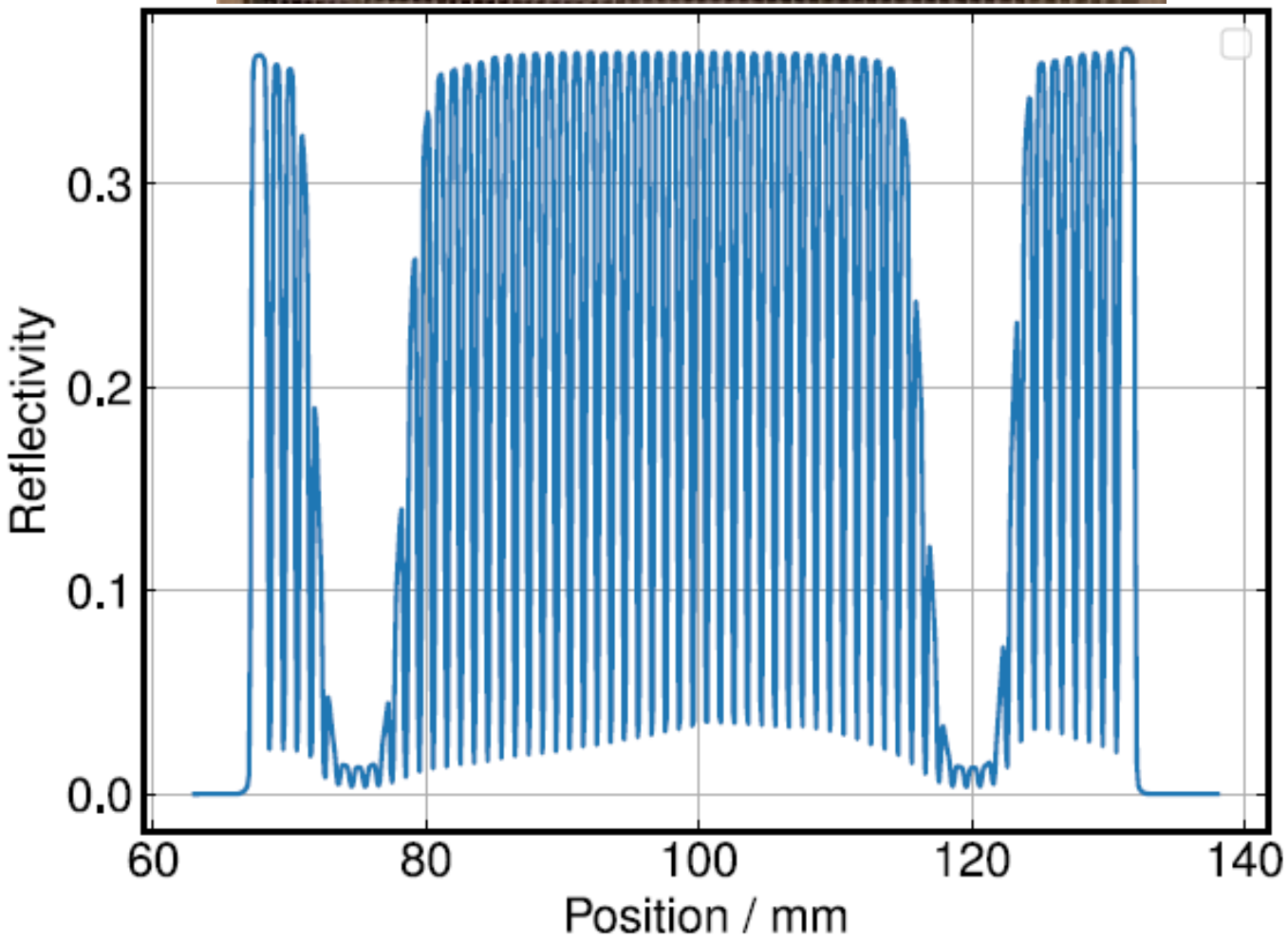


photon energy 3.6 keV
pencil beam (ap: 0.2 mm x 0.2 mm)



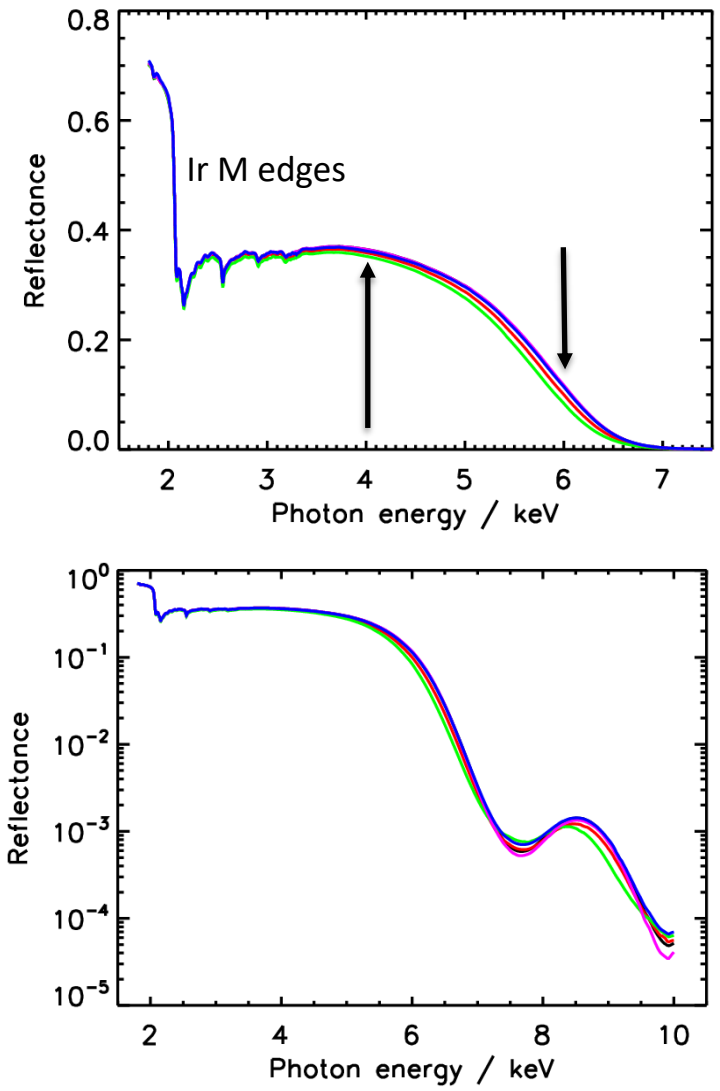
MM reflectance line scan





No reflectance when the beam is hitting the ribs or the underlying plate (due to the curvature)

Reflectance of different MM pores

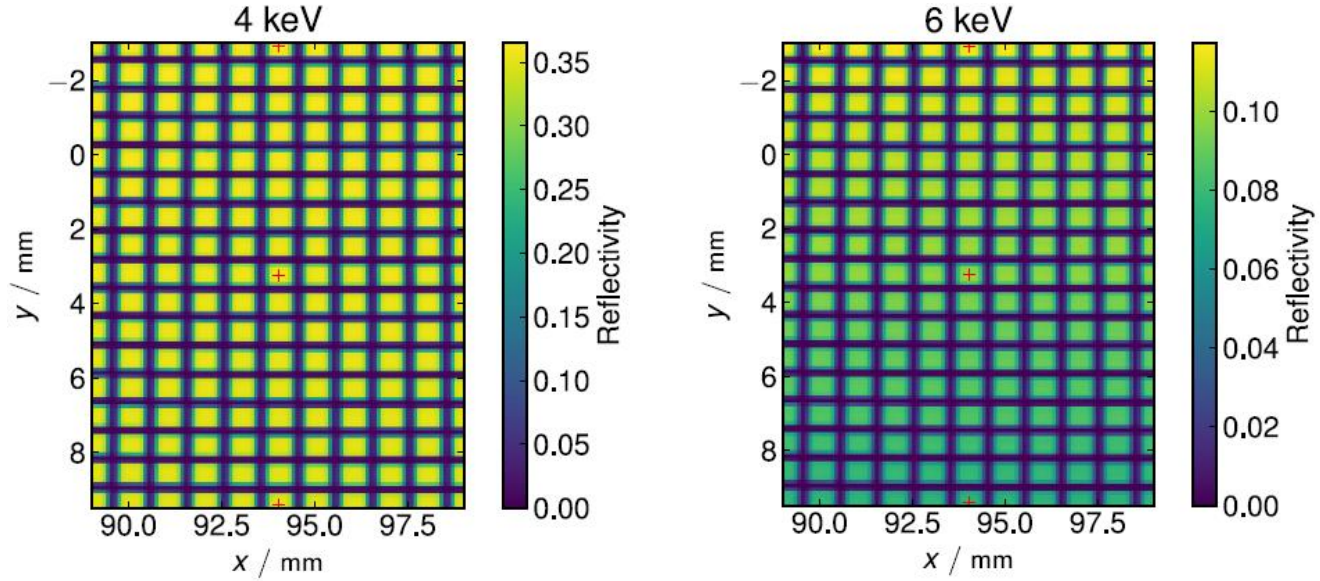


Photon energy scans through individual pores, double reflection

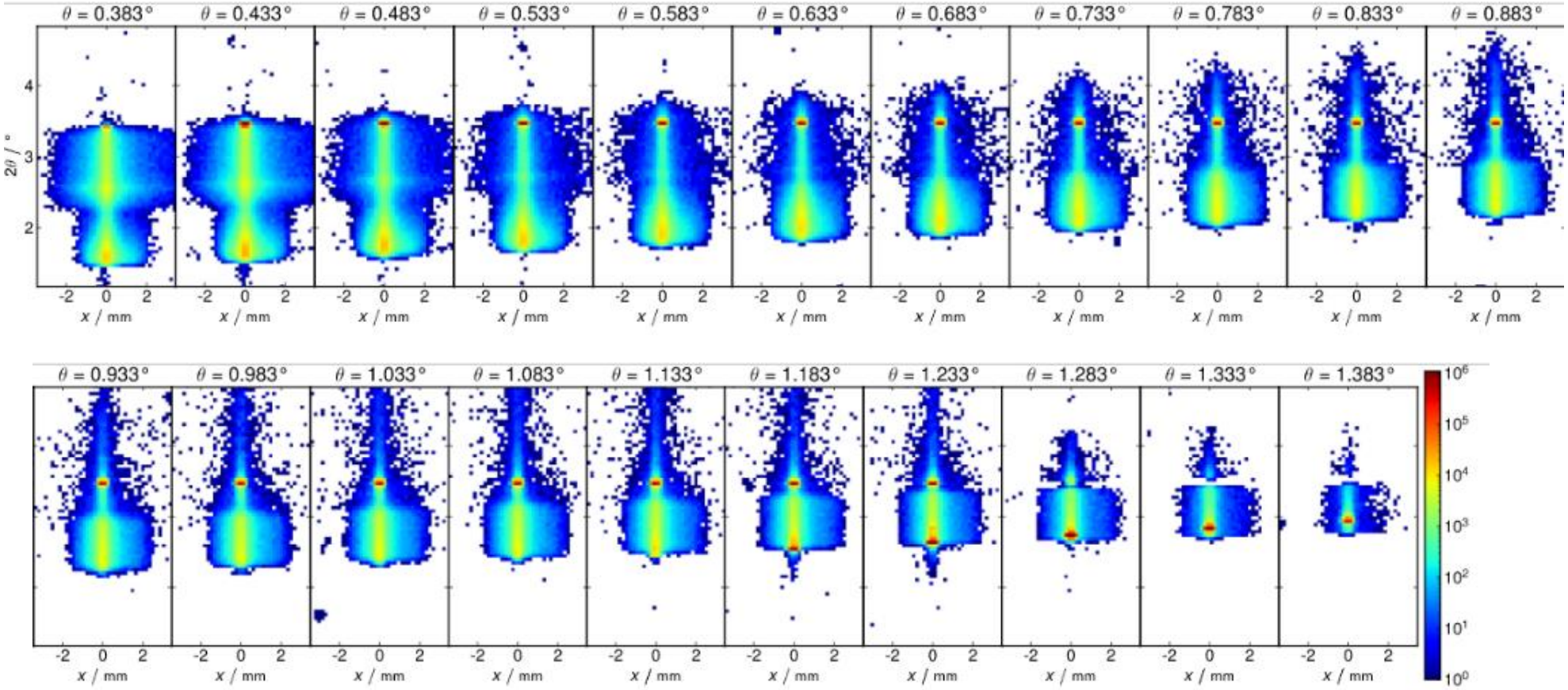
Very stable beam position required!

- pores on 3 different plates (1, 9, 17)
- 2 off-center pores for plate 1 (± 20 mm)

Raster scans at fixed angle



Double reflection, variation of the incidence angle by ± 0.5°



Earlier measurements from January 2022 on a partly coated MM which has also been measured at the PGM beamline in the energy range from 0.2 to 1.8 keV

Double reflection peaks remains always at the same position

Conclusion and outlook

- NewATHENA will be the largest X-ray telescope ever flown
- Mirror will be based on Silicon Pore Optics
- Mirror Modules are assembled and characterized at XPBF 2.0
- Energy-dependent reflectance has been measured on a Ir coated mirror module at the FCM beamline in the range from 1.75 to 10 keV
- Currently, a (partly modified) copy of XPBF 2.0 (called MINERVA) is being installed at the ALBA synchrotron radiation facility in Spain
- After final mission adoption, two additional beamlines will be installed in the PTB laboratory at BESSY II for the production of the about 500 mirror modules
- The launch of NewATHENA is currently scheduled for 2036, the budget for ESA is 1.3 G€

Acknowledgements

Levent Cibik
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Proc. SPIE **12777**, 127770R (2023); https://doi.org/10.1117/12.2689003