Si pore optics development
(ESA)

1 – Introduction: IXO mirror technology requirements

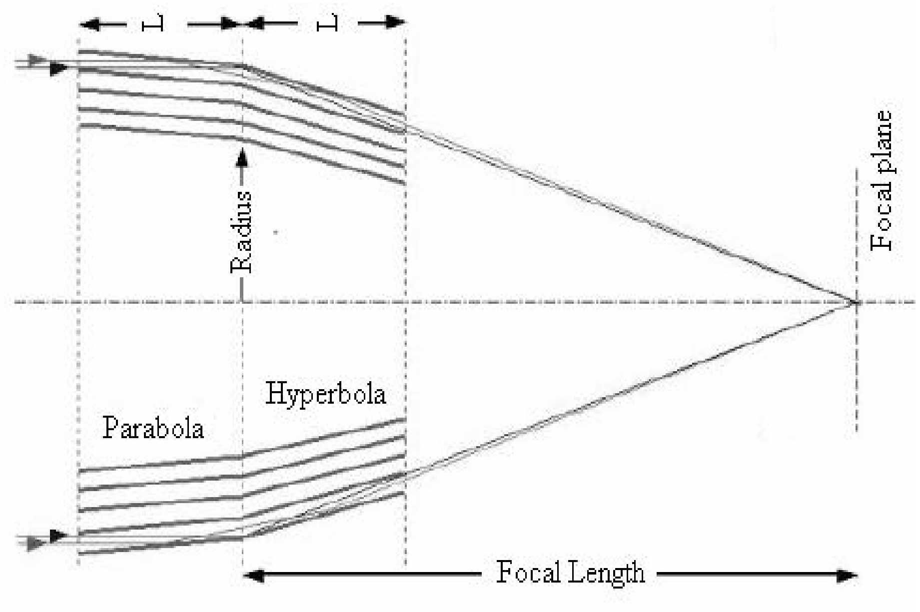
2 - Pore optics manufacturing process description

3 - Pore optics technology status

4 - Pore optics development program at ESA

5 - Summary

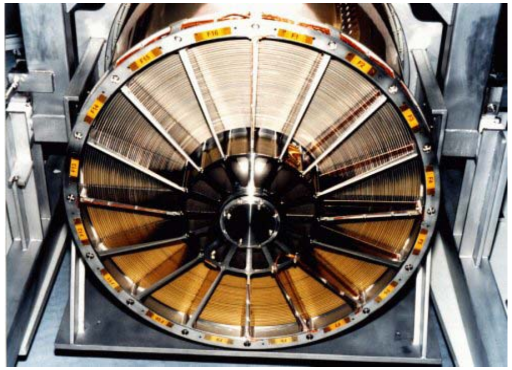
IXO mirror assembly: performance specification

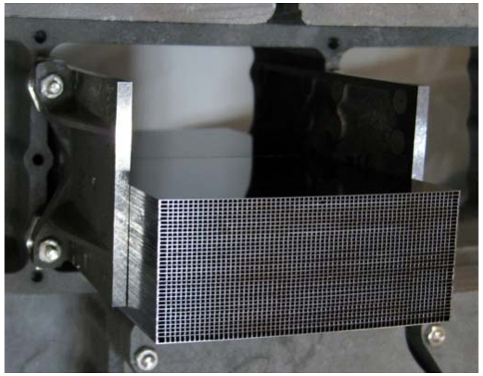


- Effective area: 3 m^2 at 1.25 keV
- Image quality: 4.5 arcsec at 1.25 keV
- Design: double-conical approx to Wolter I
- F = 20 m (accommodation constraints)
- FOV = 18 arcmin diameter (WFI)
- Mass < 2000 kg

▸A mirror technology is needed that can provide large effective area, good image quality and low mass.

X-ray mirrors technologies: image quality vs mass

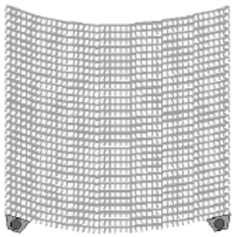


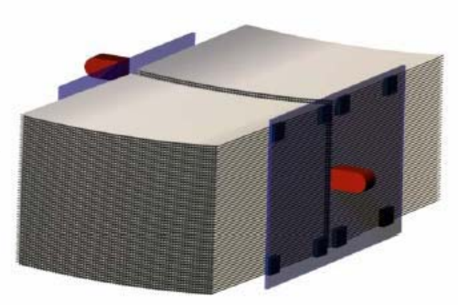


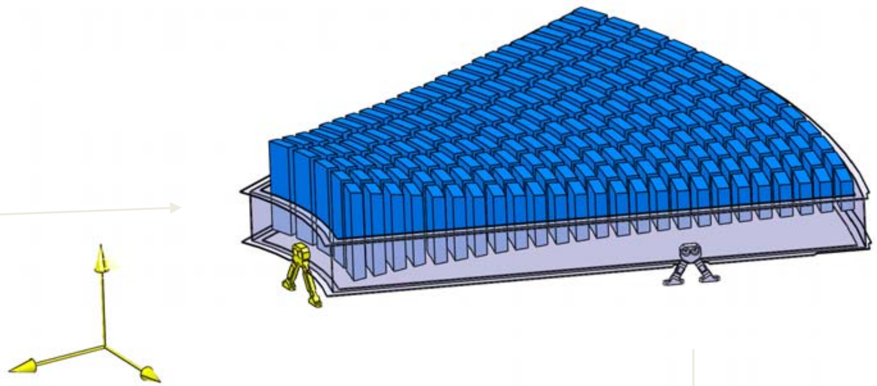
CHANDRA	XMM-NEWTON	Si pore optics
0.5″	14″	5″
18500 kg/m^2	2300 kg/m^2	200 kg/m^2
A_{eff} @ 1 keV	A_{eff} @ 1 keV	A_{eff} @ 1 keV

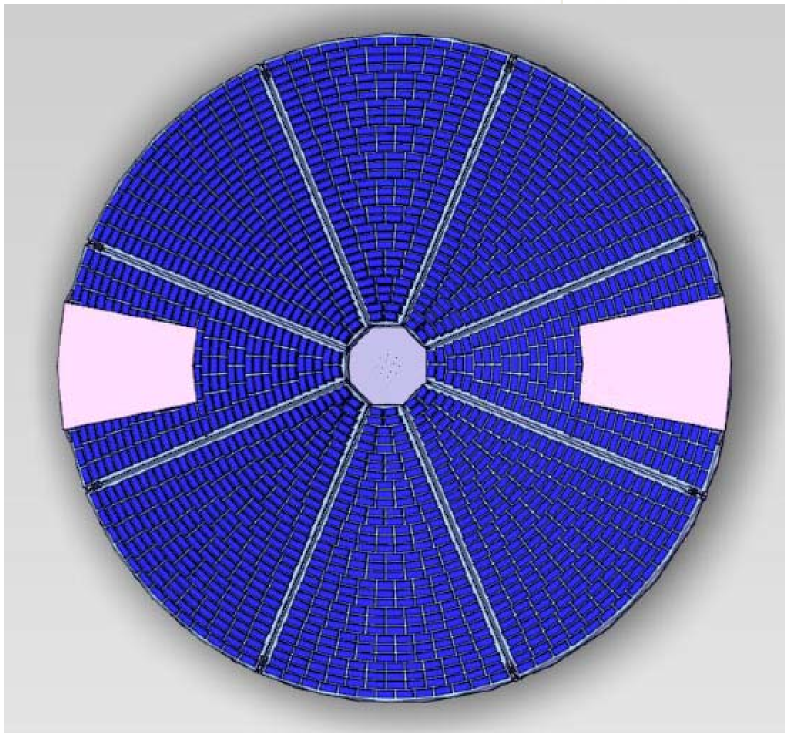
- Large effective area, good image quality and low mass not achievable with currently established technology
- A new X-ray mirror technology is needed: Si pore optics or slumped glass

IXO mirror assembly: pore optics manufacturir





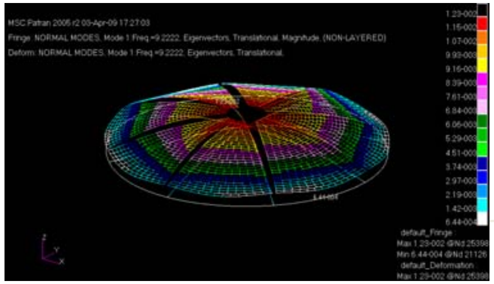


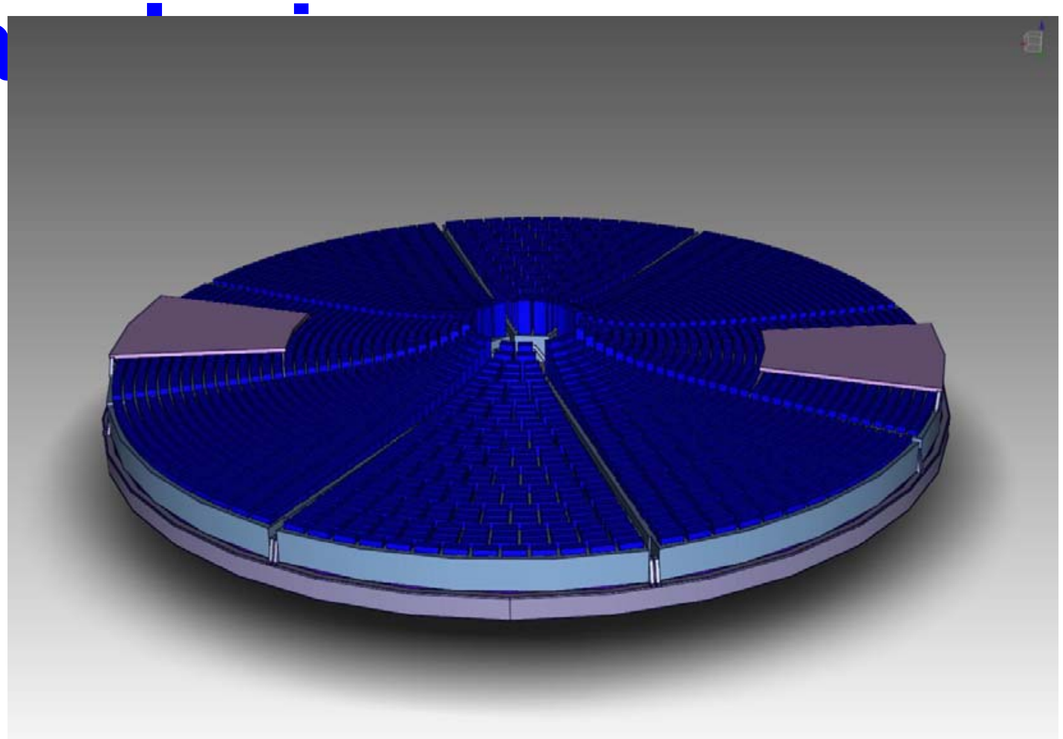


Hierarchical fabrication of mirror assembly

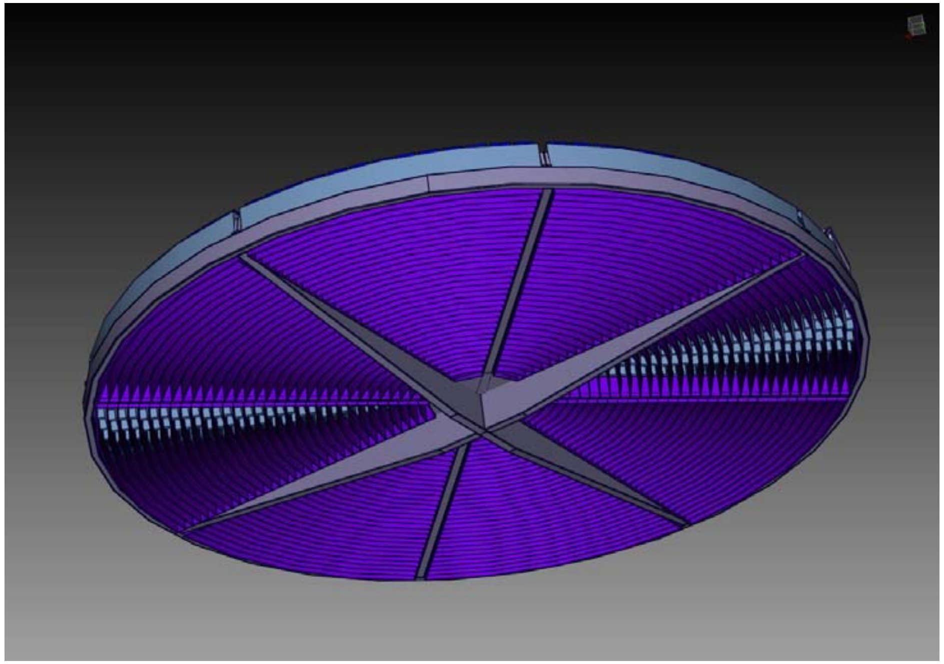
- Mirror stacks
- Mirror module
- Petals
- Optical bench

IXO mirror assembly: mechanical design and a





Cumulative modal mass in longitudinal (lateral) direction < 10% at 31 Hz (9.8 Hz)



- 1 CFRP spoke wheel: 125 kg
- 8 CFRP petals: 1056 kg
- 8 x 236 mirror modules: 568 kg
- 1 Aluminium pre-collimator: 180 kg

IXO mirror module: performance and environmental constraints

LAUNCH:

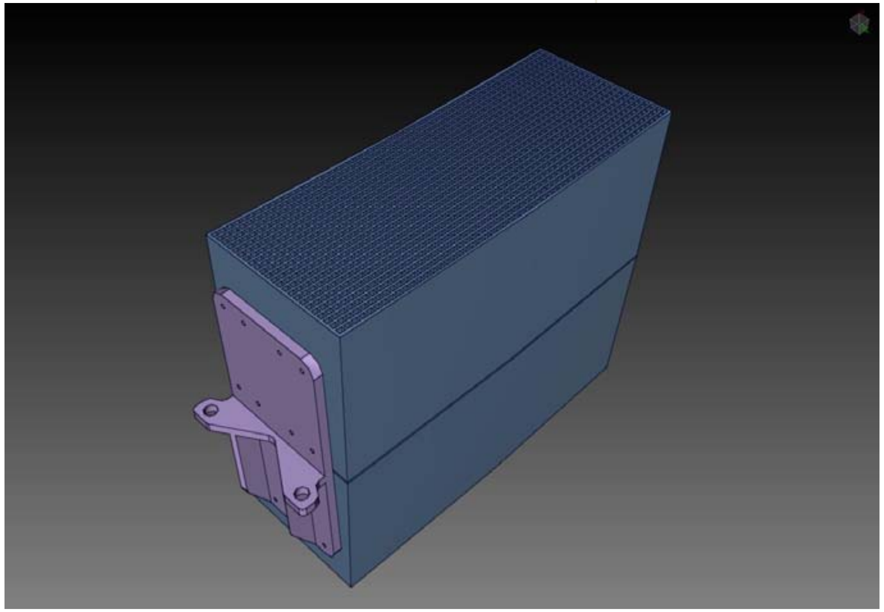
- Mechanical environment:

Dynamical behaviour: first eigen f > 200Hz

Quasistatic longitudinal acceleration: ~ 18 g (TBC – innermost MM)

- Acoustic environment:

Ariane 5 (~140 db in 20 HZ – 2.8 kHz)



IN-ORBIT OPERATION:

- Thermal environment:

operation temperature: 268 K – 293 K

axial gradient: < 11 K/m

transverse gradient: < 20 K/m

- Performance requirements:

HEW < 4.3 arcsec

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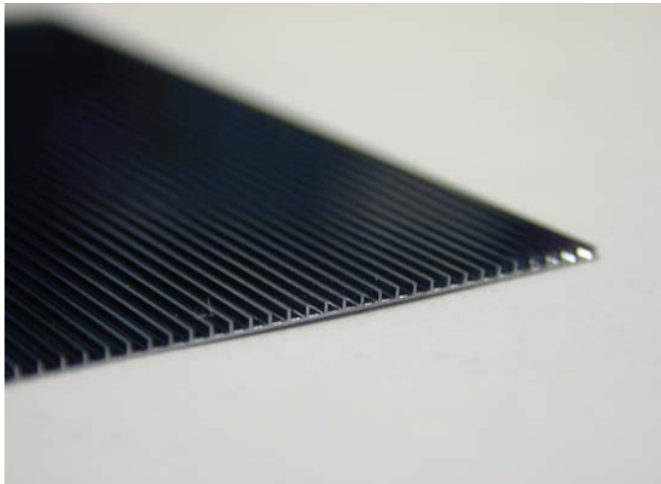
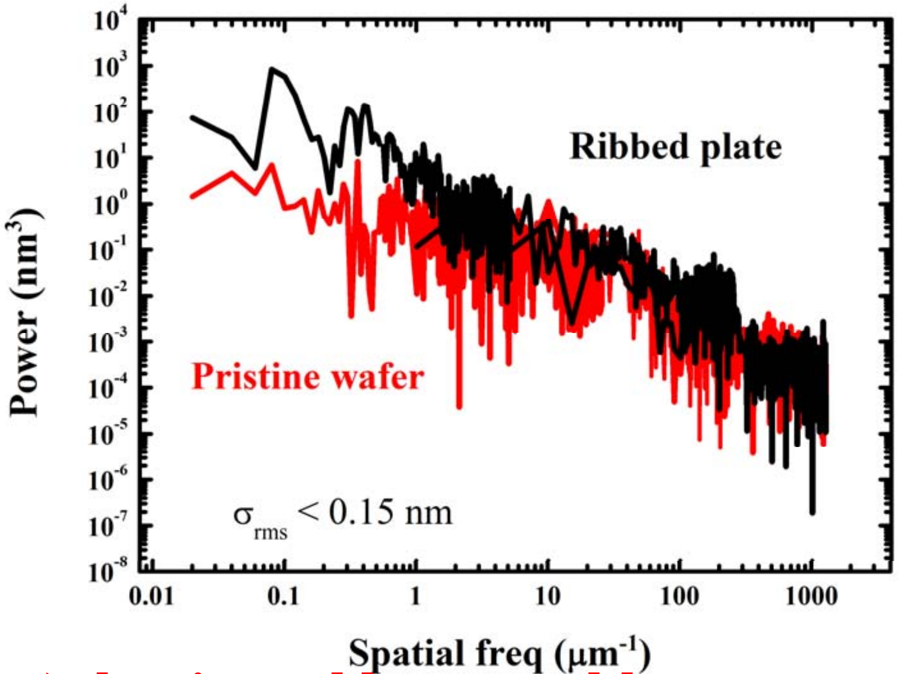
Silicon pore optics manufacturing process



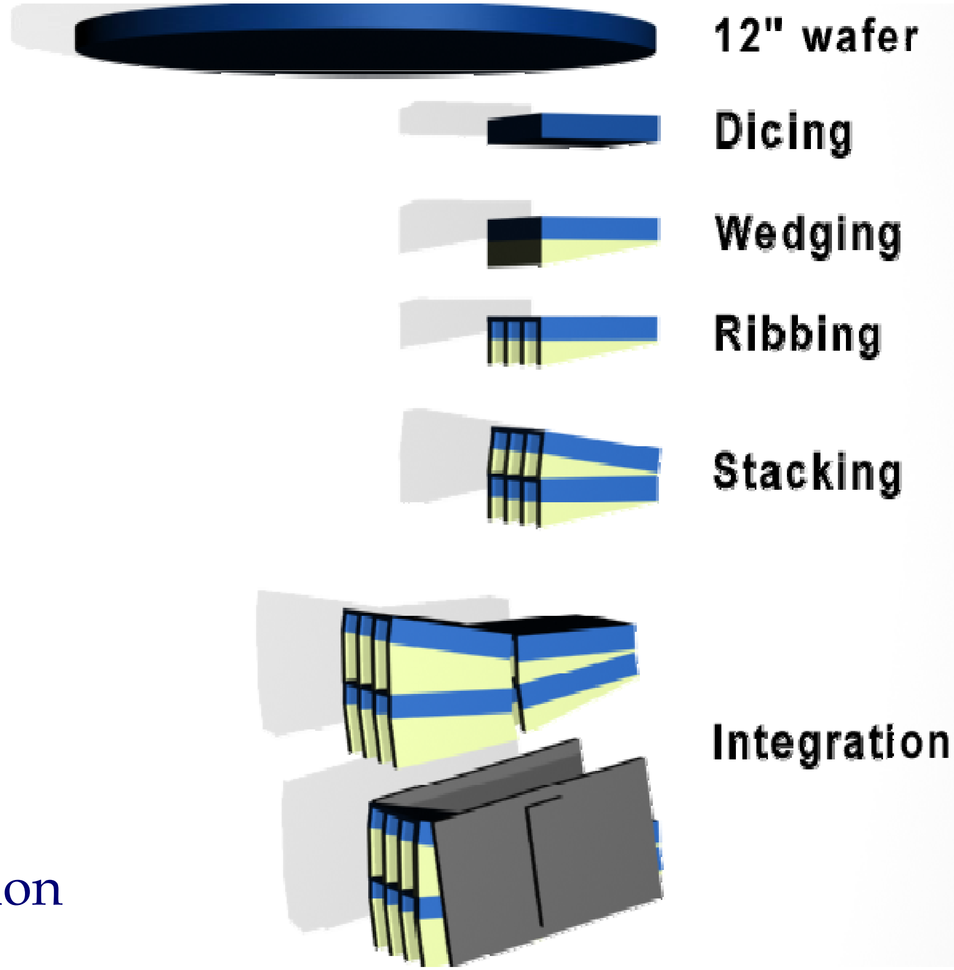
- Uses commercial high-quality 12” silicon wafers
  - plan-parallel < 0.6 μm over 300 mm
  - large-scale production, cheap
- Surface finish
  - determined during wafer production
  - 50 × 50 μm² σ_{rms} < 0.1 nm (AFM)
  - 1 × 1 mm² σ_{rms} < 0.4 nm (Chapman)
  - not significantly influenced by dicing, and ribbing



▸ **Optical performance (angular resolution, PSF) dominated by assembly process**

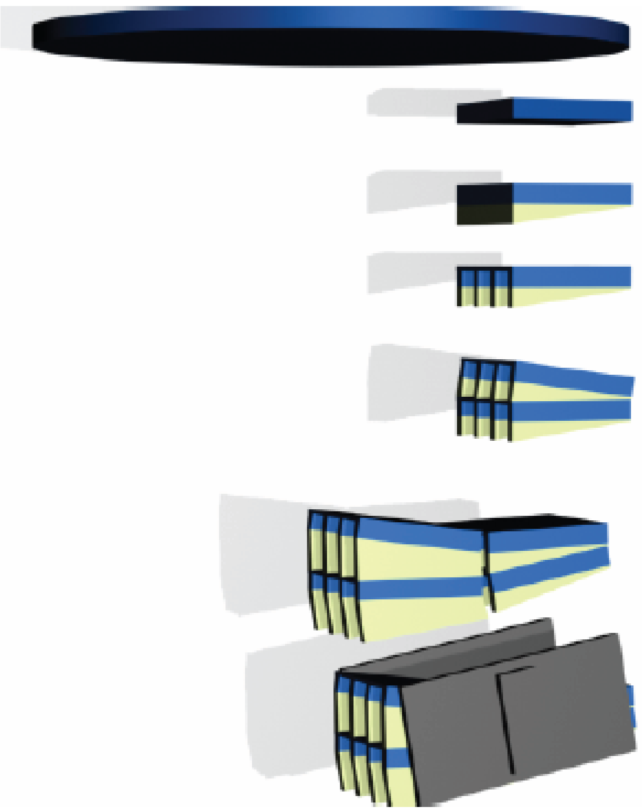
Silicon pore optics manufacturing process

- Ribbed Si plate stacking
  - Diced and ribbed (66 x 66 mm^2, 64 ribs)
  - elastically bent into a cylindrical shape
  - directly bonded on top of each other
- Stacking process established
  - Automated for routine production
  - Currently up to 35 plates
- Tandem integration
  - Developed AIT procedures
  - Installed dedicated metrology
  - Assembly directly under X-ray illumination
  - Can set and fix kink-angle between two mirrors to 1″ accuracy

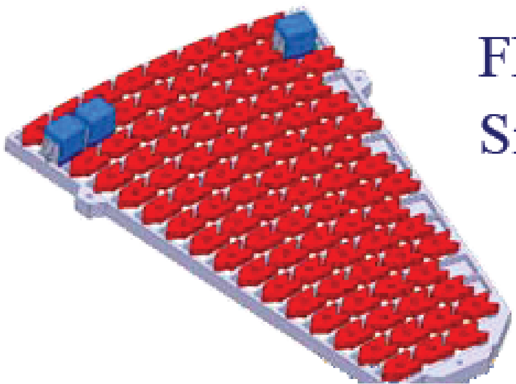


Silicon pore optics manufacturing process

- builds on established industrial processes



300mm Si wafer (industry standard)
Dicing (adapted chip dicing machine)
Wedging (customised semiconductor process)
Ribbing (adapted chip dicing machine)
Coating (customised semiconductor process)
Stacking (3rd generation stacking robot developed)
XOU assembly (standard optical engineering)
Mandrels (standard optical engineering)
Metrology (standard interferometers, autocollimators etc)
Facilities (dedicated X-ray synchrotron beamline)
FEM analysis (engineering standard)
Simulations (engineering standard)



Petal assembly (SiC breadboard tested 2007)

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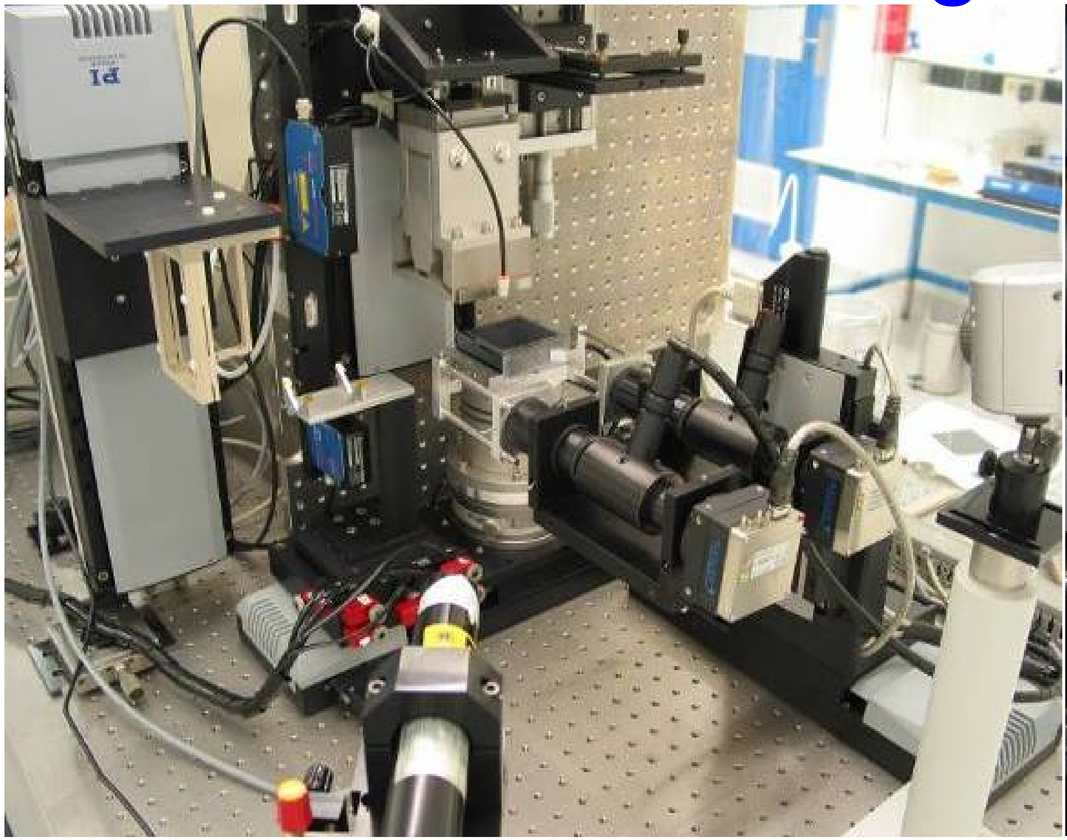
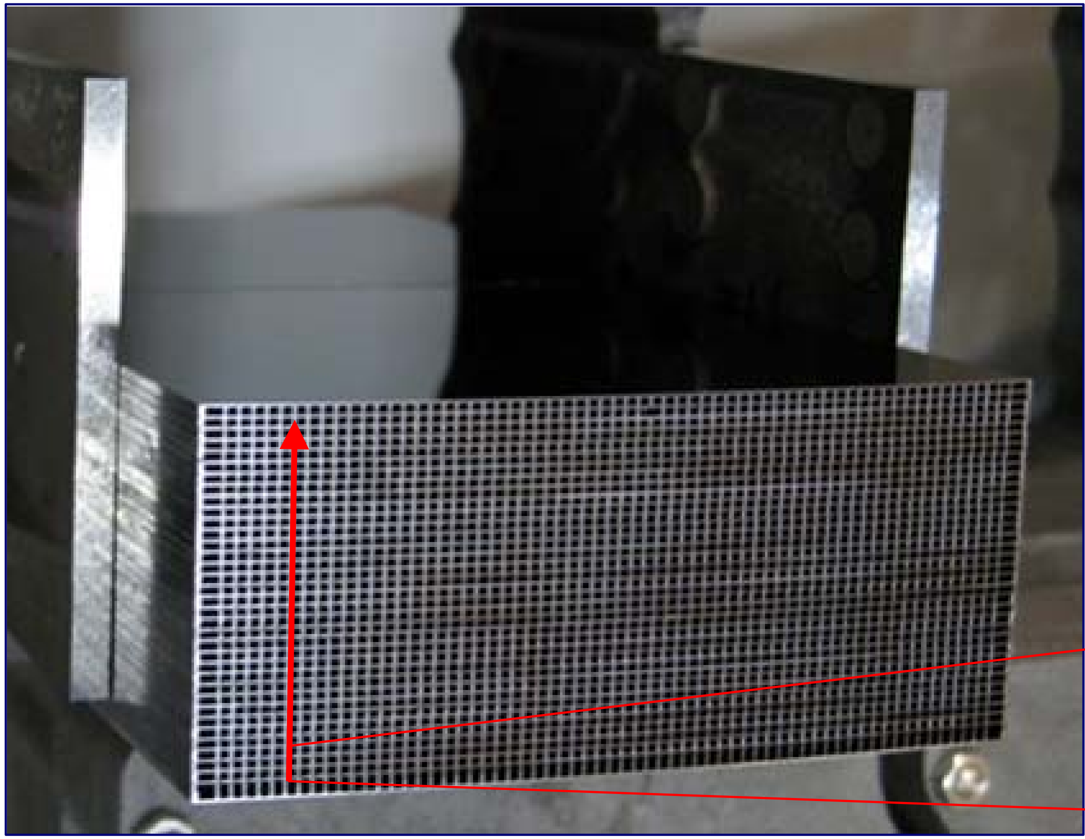
Development of a stacking robot and test/integration facility

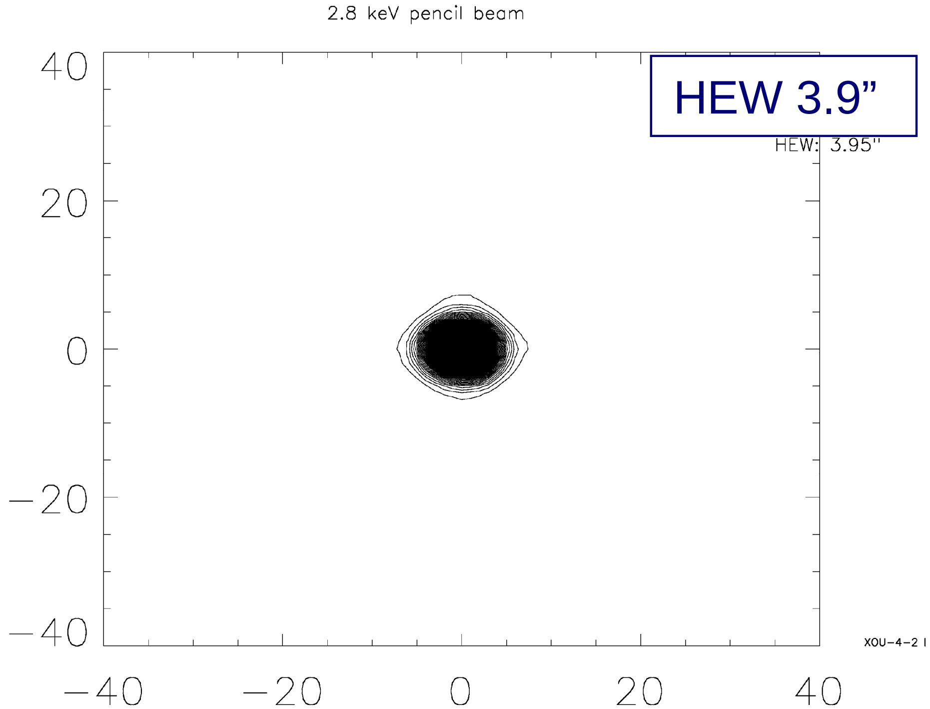


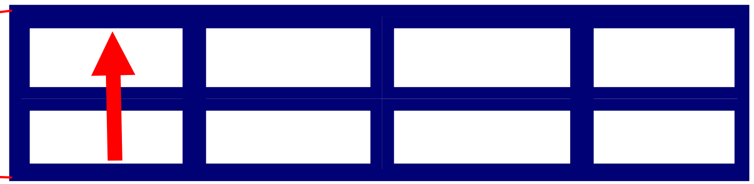
Robotic stacking of ribbed plates
Table-top equipment
Full-area real-time interferometer
Cost-effective commercial parts

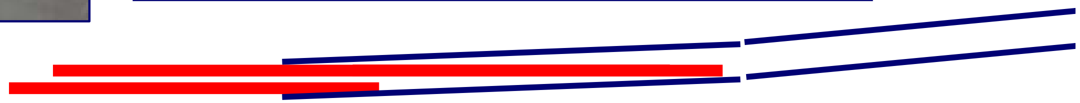
Test chamber at BESSY2 facility
Compact and precise hexapod
3D angle metrology with autocollimators
3D Position metrology

Pencil beam metrology at BESSY





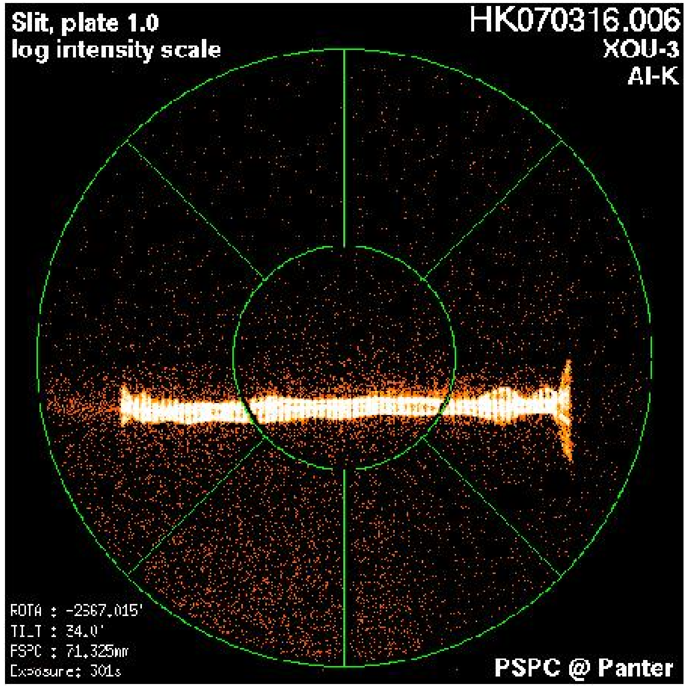




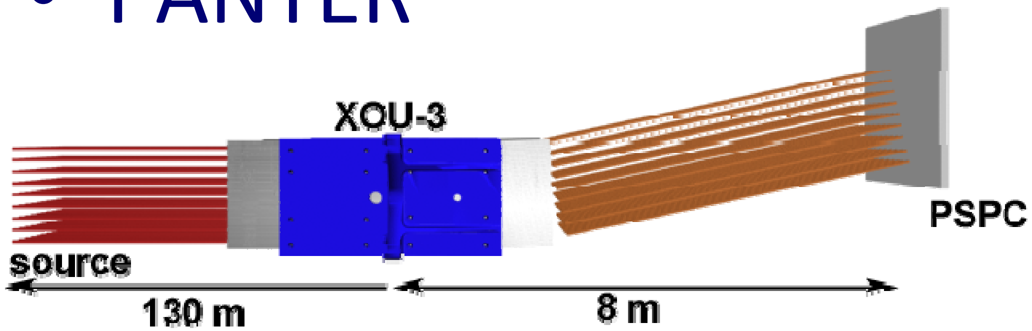
50 μm X-ray beam,
scans over full length of mirror

Measured Mounted Optics,
Single pore, double reflection:
4“ HEW

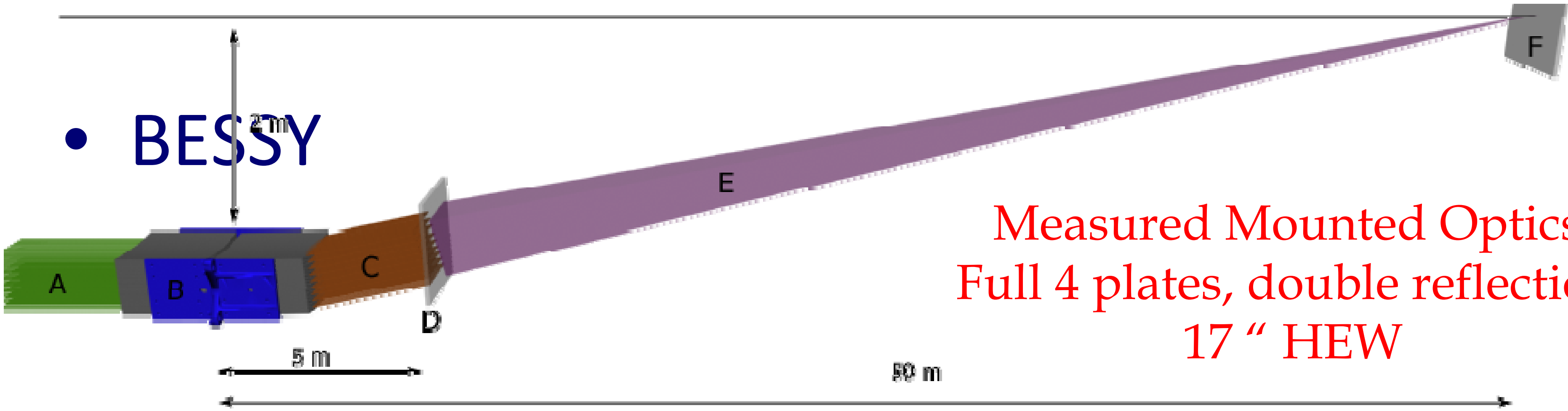
Complementary full beam test at Panter



- PANTER

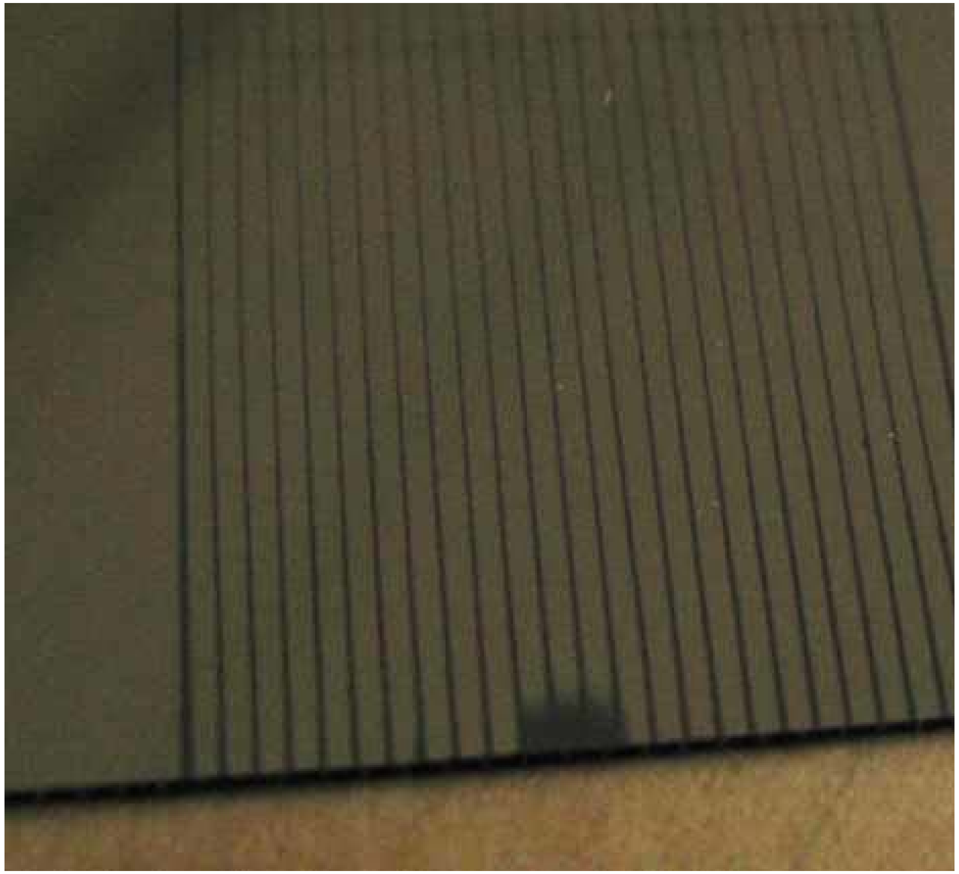


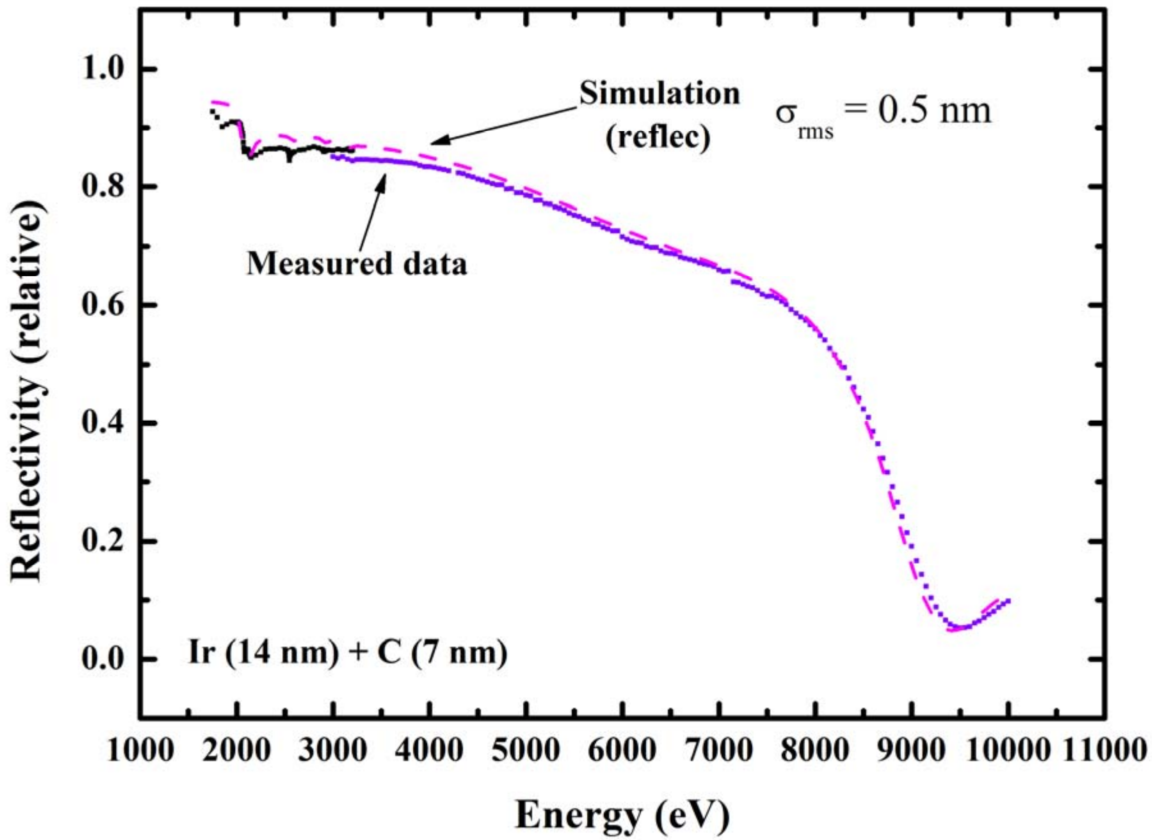
- BESSY



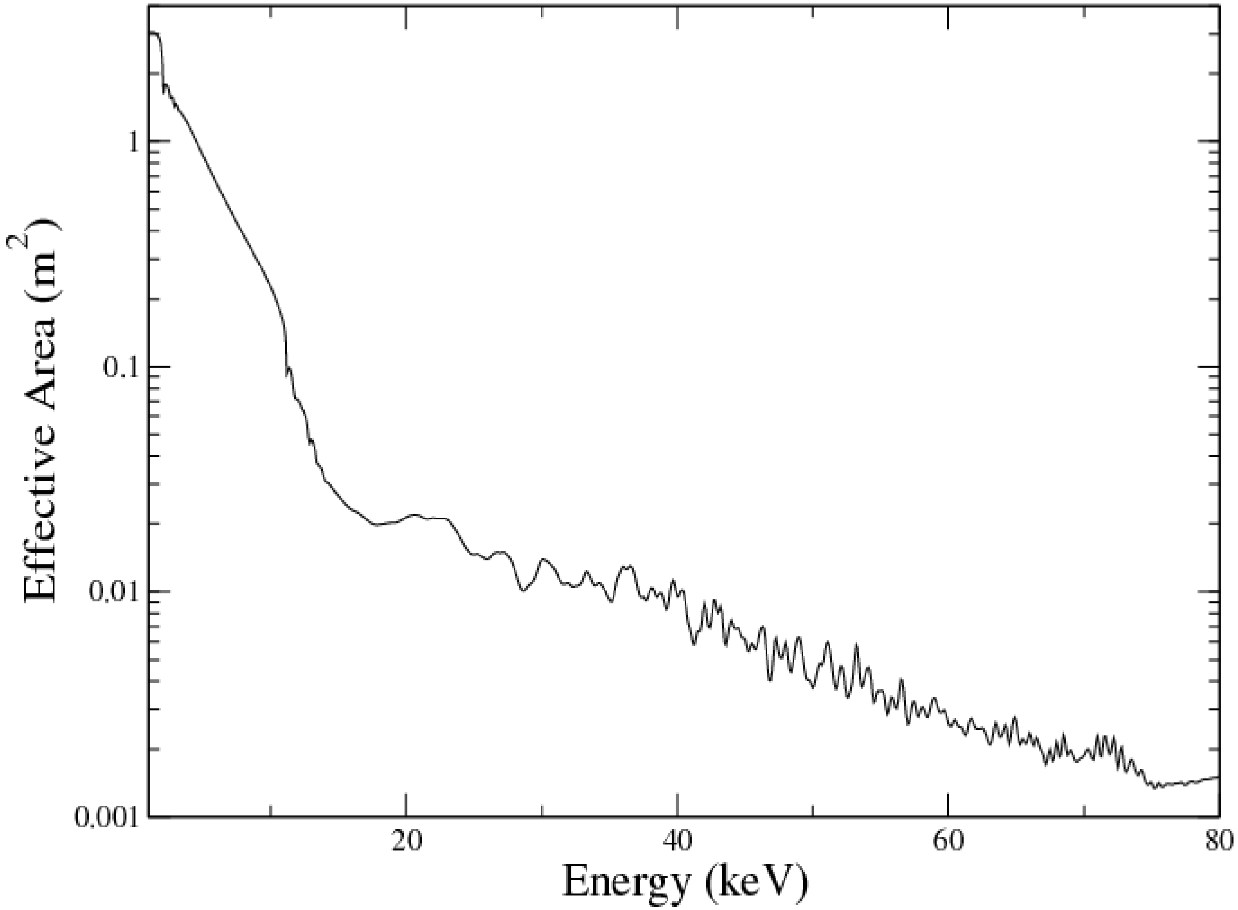
Measured Mounted Optics,
Full 4 plates, double reflection:
17 " HEW

Ir + C overcoating (DNSC)





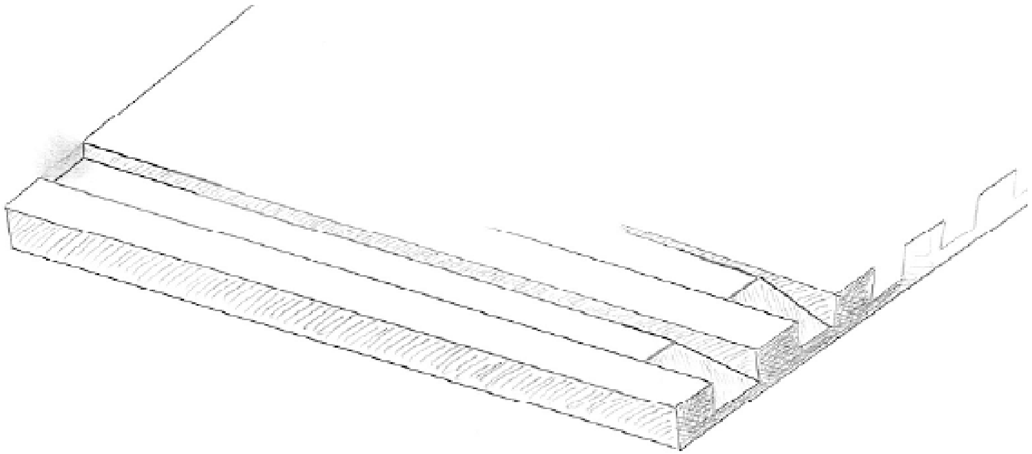
IXO mirror assembly: high E performance



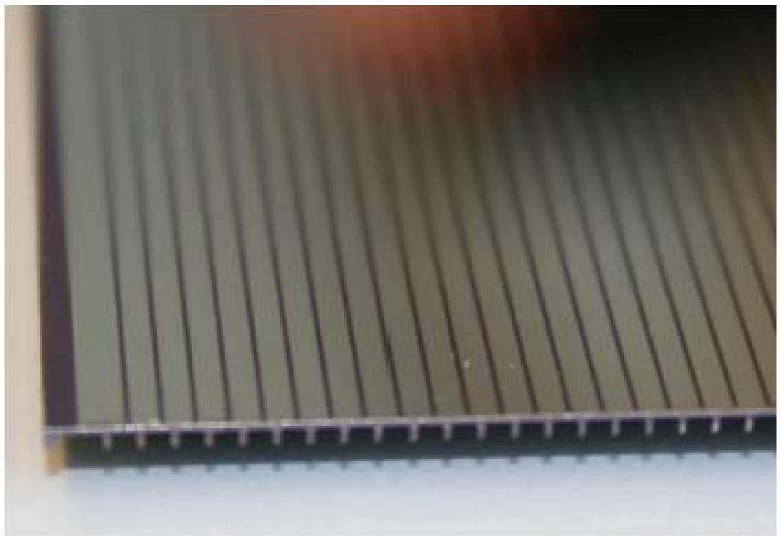
With JAXA/ISAS multilayer design (courtesy H. Kunieda) on mirrors with grazing incidence lower than 0.342° (R< 0.477 m)

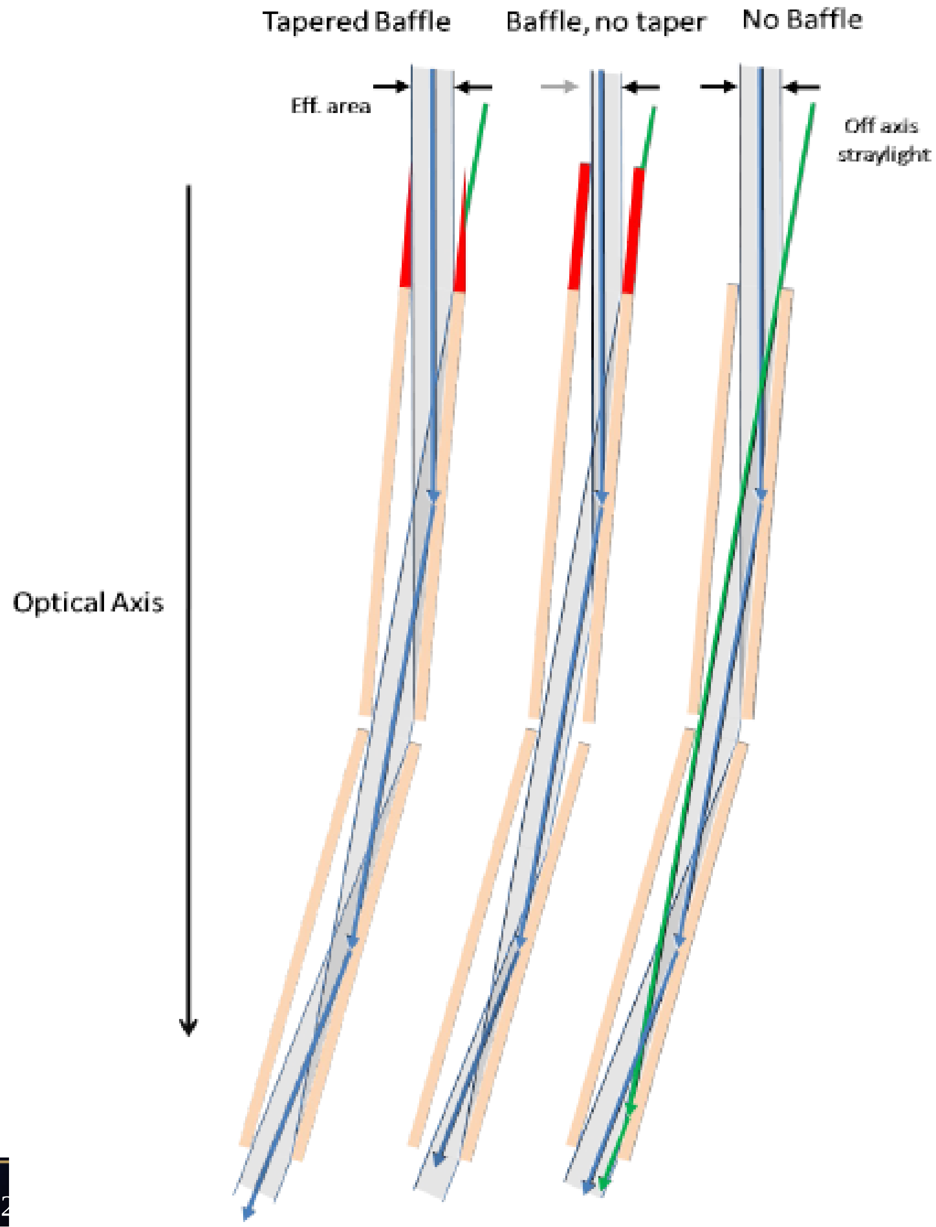
Aeff (30 keV) ~ 150 cm²

Mirror module straylight rejection baffle (running activity)

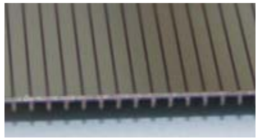
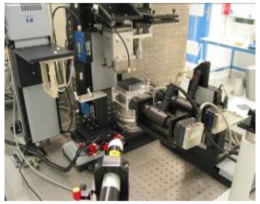
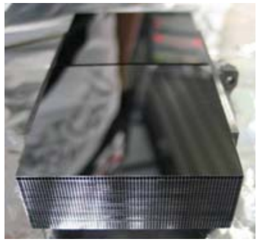
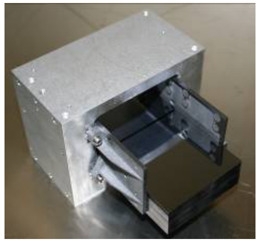
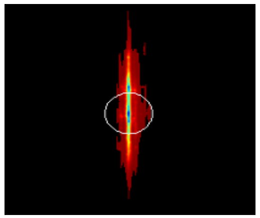
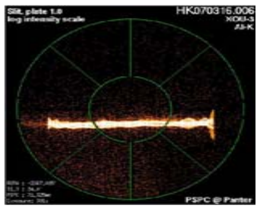


Artist's impression of tapered baffle



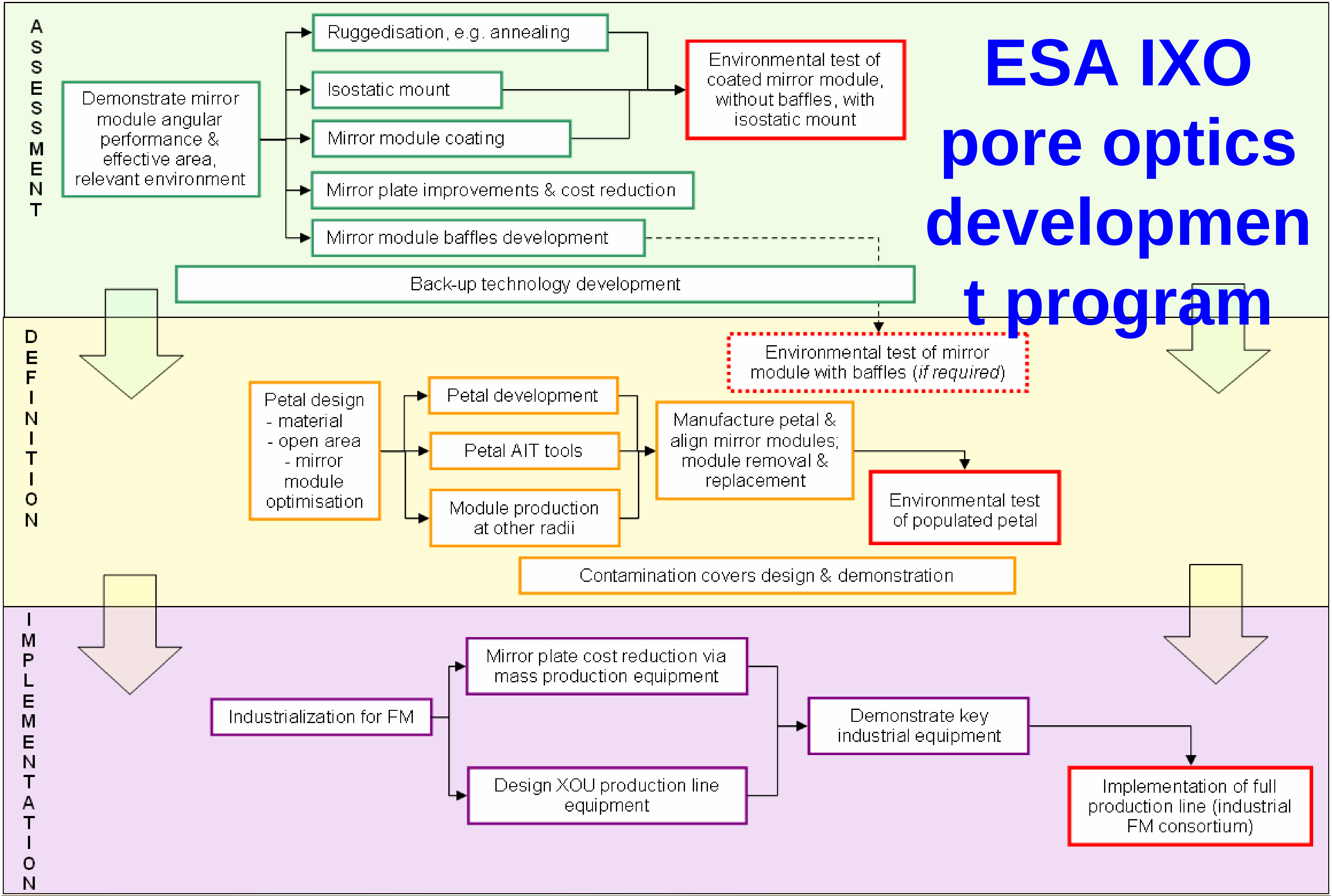


IXO Optics – Development & Production

Steps	Done		Next
Plate production	Industrial process	 	Reduce cost
	Wedged, coated, non-conical		Different sizes
	500 produced		
Stack production	Automated	 	Improve HEW
	Particle inspection, cleaning, bending, interferometry, stacking		
	200 produced		
Module production	Design	 	
	Integration method		
	Mounting method		
	4 produced		
Module validation & qualification	Synchrotron & beam testing in place	 	Environmental testing
	Ruggedness assessment		Focal plane testing
Petal production	Design	 	
	1 produced		
Petal validation & qualification	Preliminary X-ray testing		Environmental testing
			Focal plane testing

Si pore optics development
(ESA)

ESA IXO pore optics development program



Summary:

- **Challenging requirements** on optics technology for IXO
- **Encouraging results** from industrial developments of Silicon Pore X-ray Optics Technology
- ESA has selected the **Silicon Pore Optics as the baseline mirror technology** in its IXO development plan for 2008-2012
- **A Si Pore Optics technology development programme** is being implemented by ESA, addressing mirror performance, coatings, baffling, environmental qualification and mass production issues