cosine

Beyond XMM-Newton: development of the largest X-ray mirror for Athena

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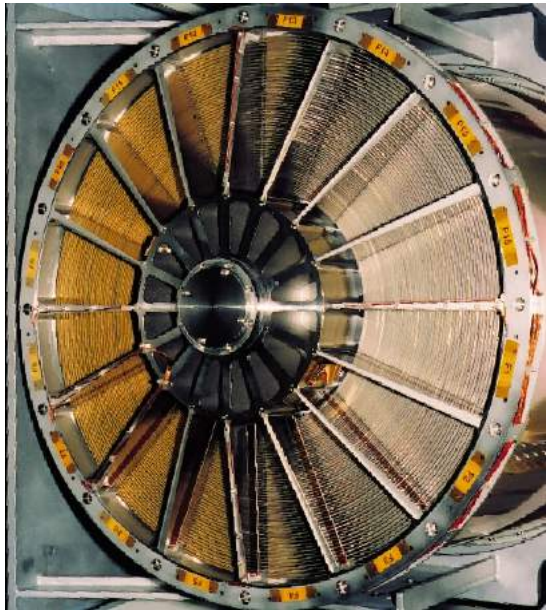
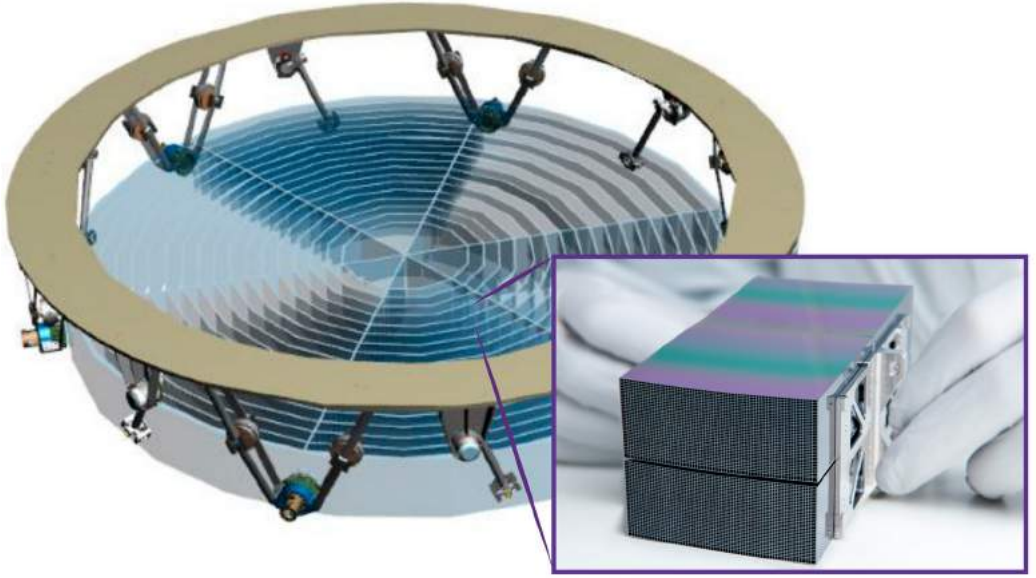
From XMM to Athena: New Technology for Largest Optic



XMM-Newton

- 0.35 m radius
- Ni shell replication
  - Concentric shells



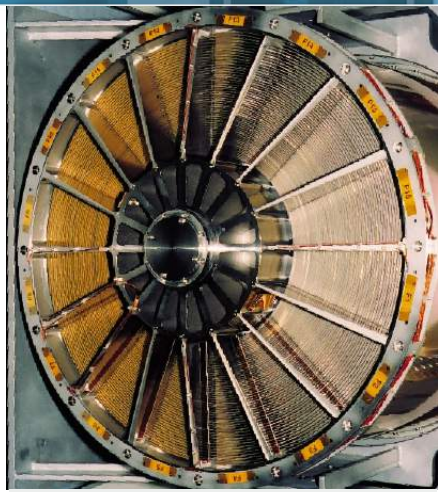
Credit: ESA. Cosine and ACO Team

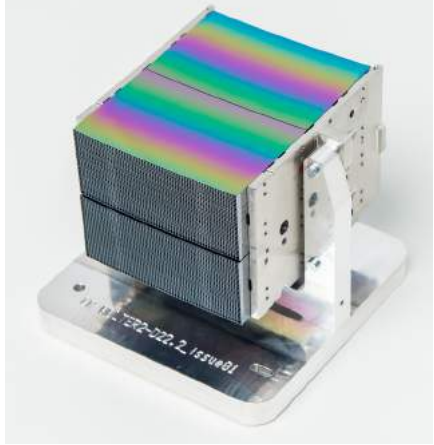
Athena

- 1.2 m radius
- Silicon Pore Optics
  - Stacks of mirrors form mirror modules
  - Mirrors diced from Si wafers from semiconductor industry
  - Combines into the largest X-ray mirror ever flown

Silicon Pore Optics: Cost-Effective Increase of Mirror Area

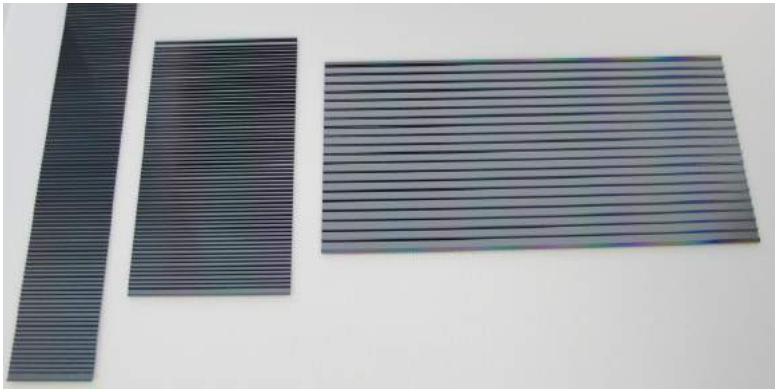
	XMM-Newton	Athena
Technology	Ni shell replication	Silicon Pore Optics
Outer radius	0.35 m	1.2 m
Mirror thickness	0.47 - 1.07 mm	0.17 mm (0.11)
Number of mirrors	58 shells * 3 telescopes = **174**	1080 shells in 606 modules = **87,000**
Performance:		
Effective area (1 keV)	0.14 m^2	1.9 m^2
PSF HEW (1 keV; on axis)	13 arcsec	5 arcsec

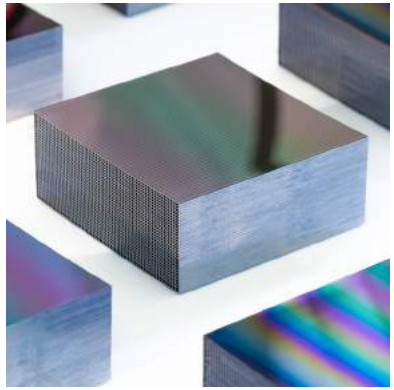




- Modular design decouples the problem of large area and high performance

Robotic Manufacturing: Consistent High Quality Optics

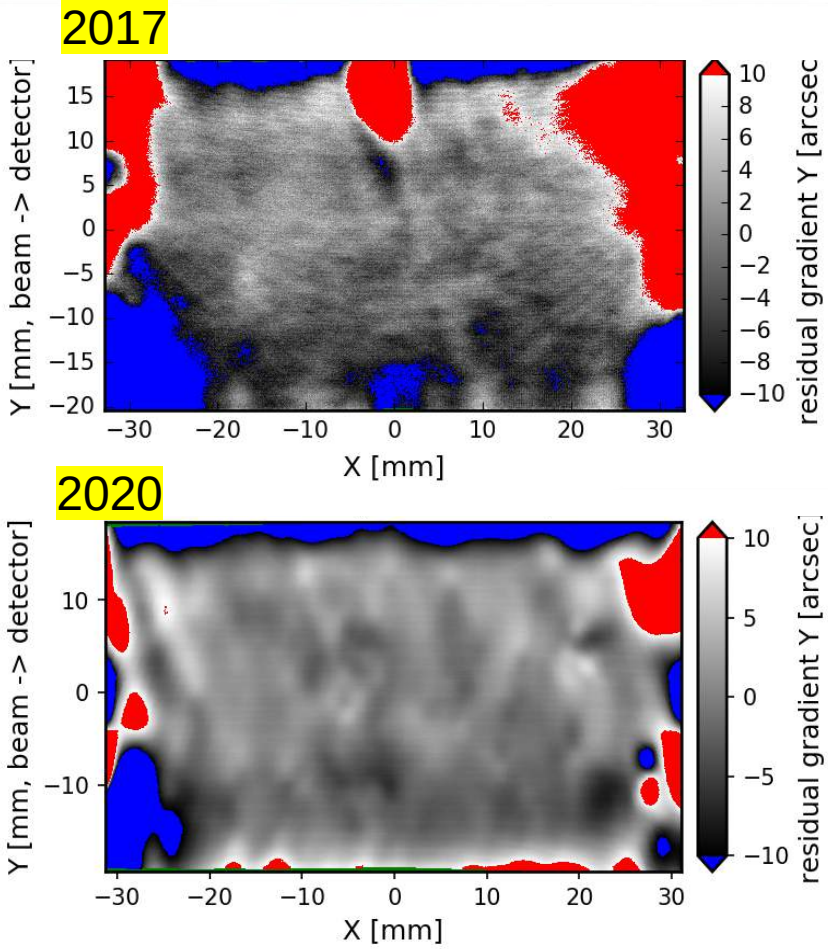


- Employ processes and equipment from semiconductor industry
  - Plates cut from Si wafers, pores carved out to create ribs
- Robotic, automated, cost efficient stacking of plates
  - Combine into mirror modules to form modular optics
- Recent developments: improved reproducibility and cleanliness.
  - New wetbench will automate part of the coating process.

Fast Progress in Improving Optical Quality

- Past years: identified sources of slope deviations in the mirrors (red/blue)
  - Measured thickness of the plates down to nm
  - Developed numerical model of stacks
  - Performed stacking experiments
- Implemented substantial improvements
  - Plate defects addressed
  - Plate cleaning and handling improved
  - Robotic stacking optimized
- Remaining issues along the edges are understood, solutions are being tested right now.



X-Ray Beamline Measures Performance Improvements

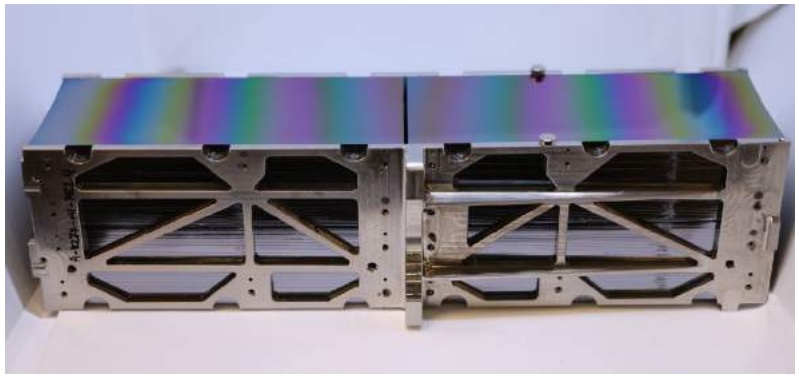
	XOU-066 2019	XOU-067 2019	XOU-92 2020
Half-energy width (arcsec)	17.5	13.2	9.9

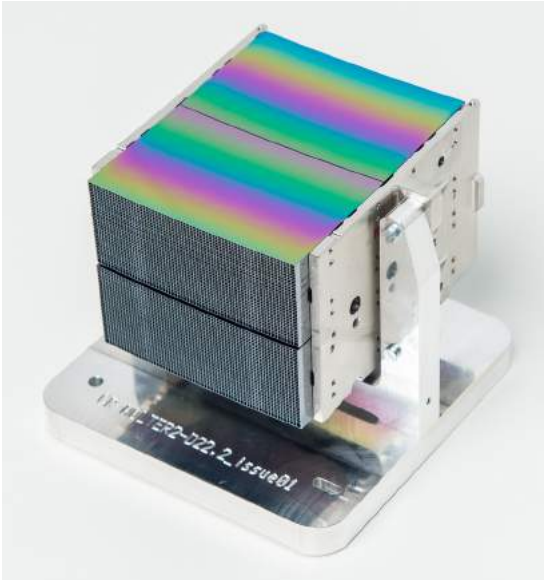
- Outer-radius XOUs (2-reflection focusing system).
  - Provide the bulk of the effective area
- Half-energy width measured for 34 plates, central 70% area.
- SPO have surpassed XMM performance.
  - Development continues in order to meet 5 arcsec requirement for Athena.

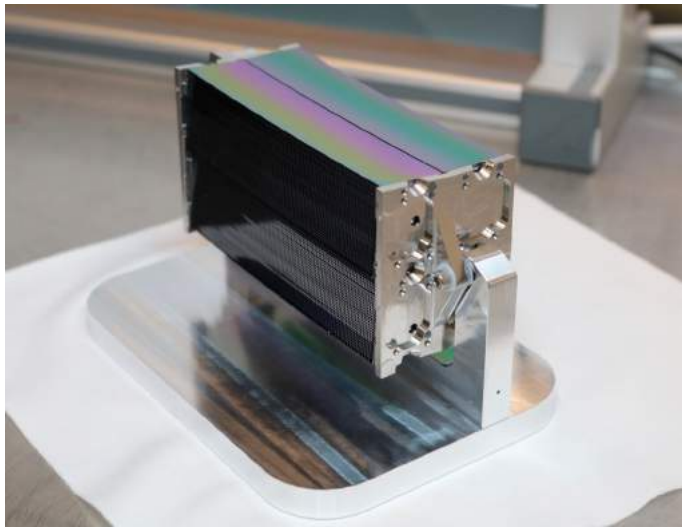
1.6 keV X-ray pencil-beam at BESSY, Berlin

Successfully Produced Mirror Modules for 3 Radii

Athena's inner ring (R=277 mm), middle (737 mm), outer (R=1500 mm)







Conclusions

- Improving on large X-ray optics beyond XMM-Newton requires a new technology: Silicon Pore Optics.
- Robotic stacking of mirror plates to mass-produce a large number of optics modules.
  - Optimizing reproducibility and cleanliness.
- Large effort in understanding slope deviations.
  - Substantial improvements achieved in cleanliness and optical performance.
  - Remaining issues understood and currently being addressed.
- On track for the Mission Adoption Review in 2022, and launch in 2031.

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