IXO TWG January 2009 Boston

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IXO System Studies and the IXO Optics
The Si Pore Optics
The predicted performance

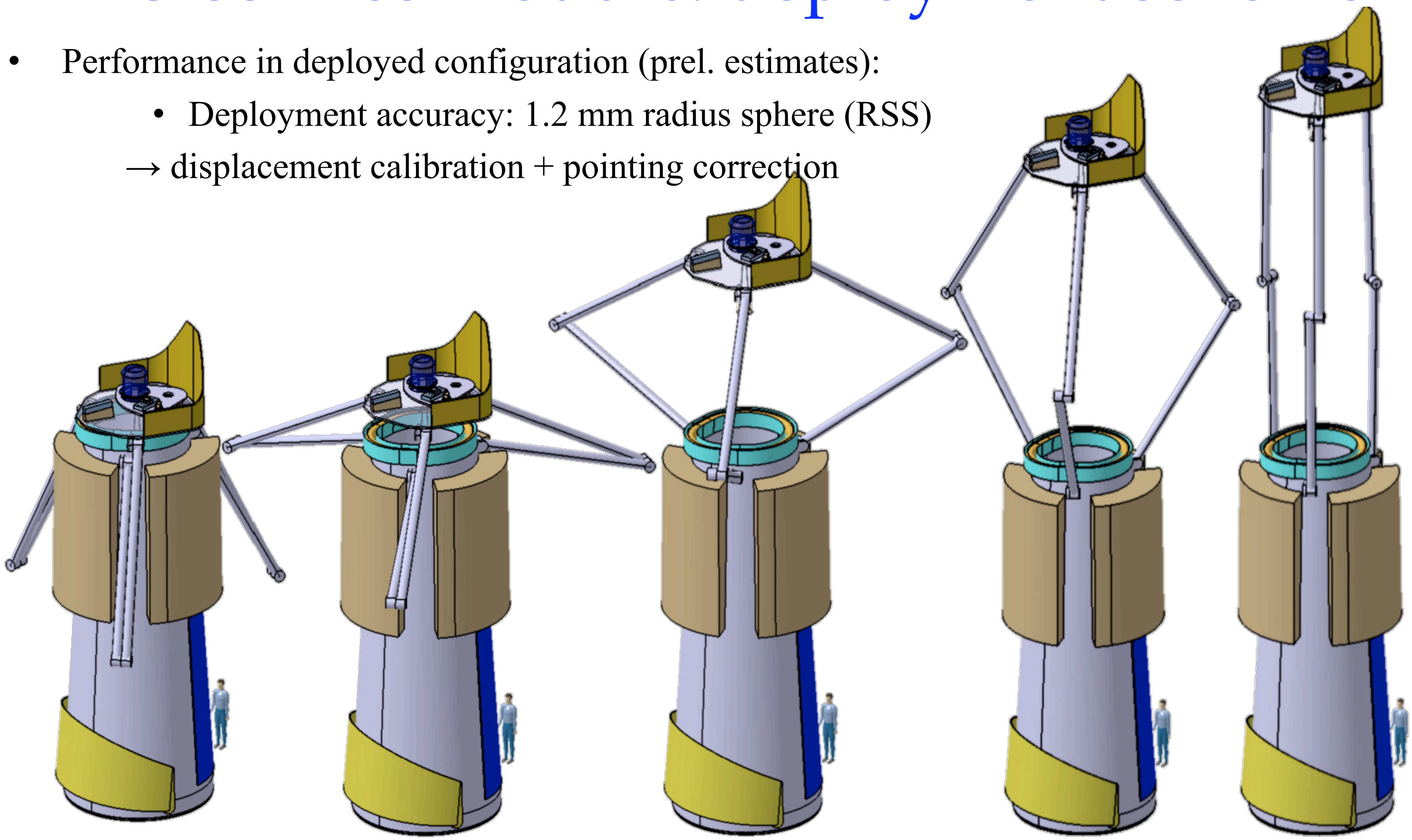
ESA+NASA - IXO System Studies and Optics

- **ESA CDF + NASA MDL - Optics Accomodation**
  - 20 m focal length – minimum required to get the specified effective area at > 6 keV independent of the mirror technology.
  - Increase to 25 m focal length would improve the effective area > 10 keV – by at least a factor of 2.
  - For the baseline Si optics design the full aperture radius 0.25 m < R < 1.9 m is required to meet the specification of 3 m^2 at 1 keV .
  - The aperture coverage required to meet the area specification for the baseline slumped glass optics design is slightly less.
  - Both studies allocate 1800 kg to the mirror module – this is limiting the low energy effective area for both technologies.
  - Both studies include a baffle/skirt to close off the extension volume – this stray light protection is required for the gratings.
- **IXO CDF telescope consolidation study** (4th Feb → 16th Mar 2009)

IXO service module: deployment scheme

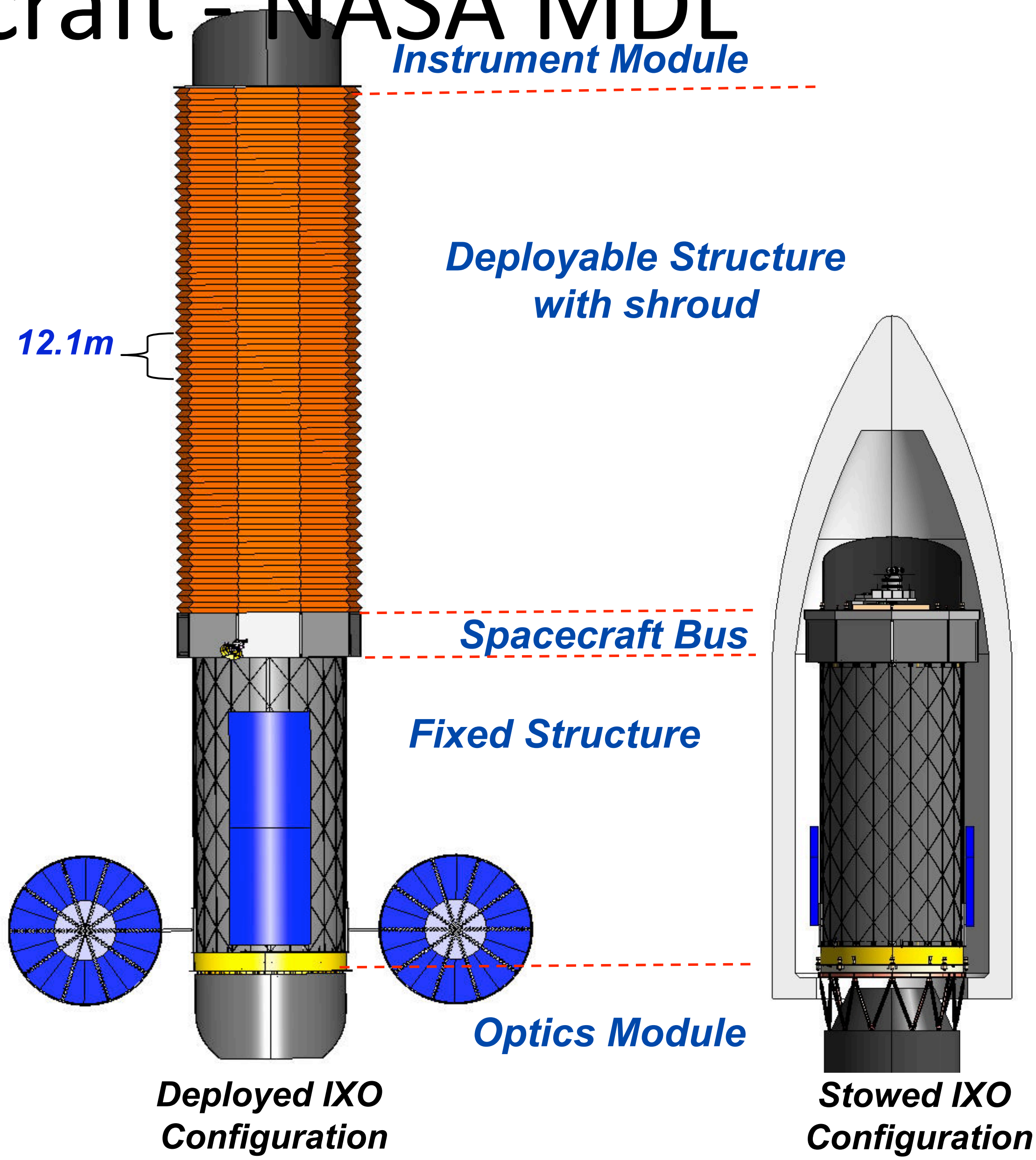
- Performance in deployed configuration (prel. estimates):
  - Deployment accuracy: 1.2 mm radius sphere (RSS)

  → displacement calibration + pointing correction

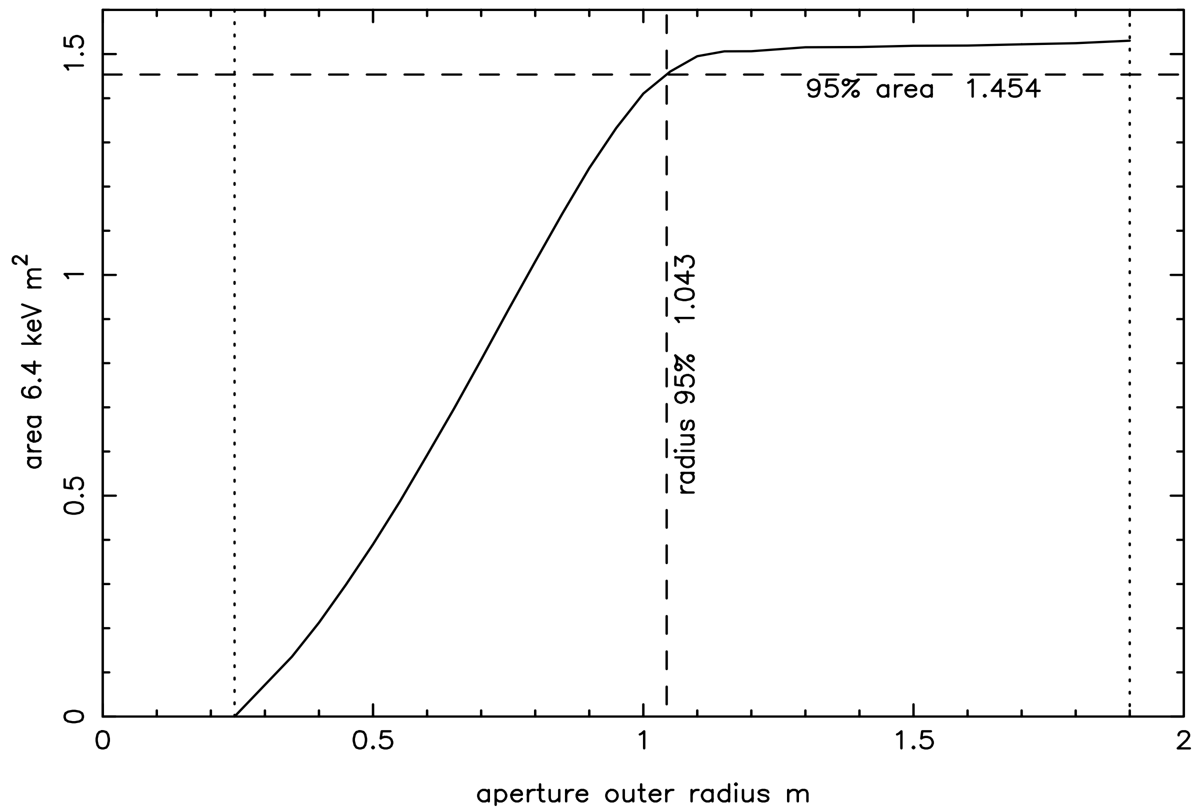


IXO Spacecraft - NASA MDL

- Observatory Mass ~6300 kg (including 30% contingency)
- Launch on an Atlas V 551 or Ariane V
- Direct launch into an 800,000 km semi-major axis L2 orbit
- The observatory is deployed to achieve 20 m focal length
- 5 year required lifetime, with expendables for 10

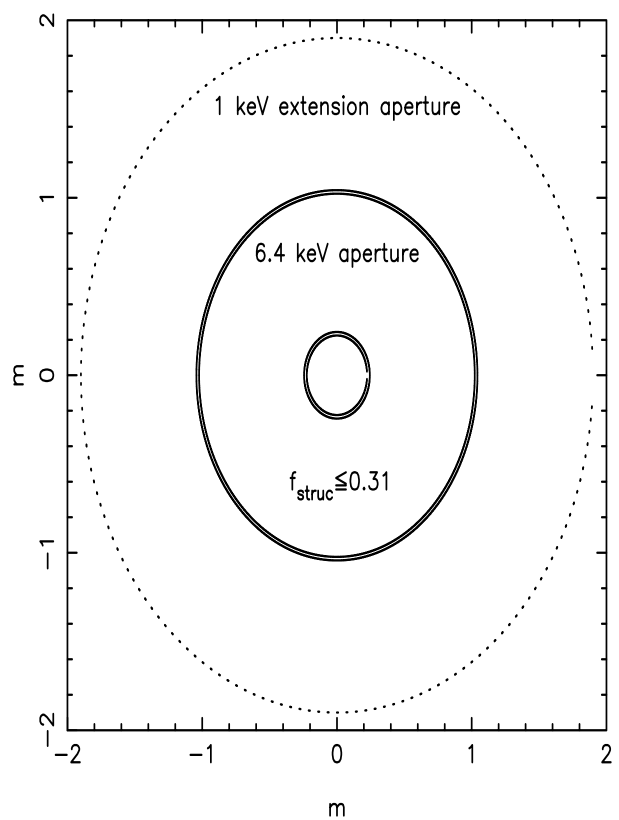


Maximising the area at 6.4 keV



The minimum radius is set by the maximum axial length of available Si plates
Increase in area with radius for Si pore optics with NO support structure

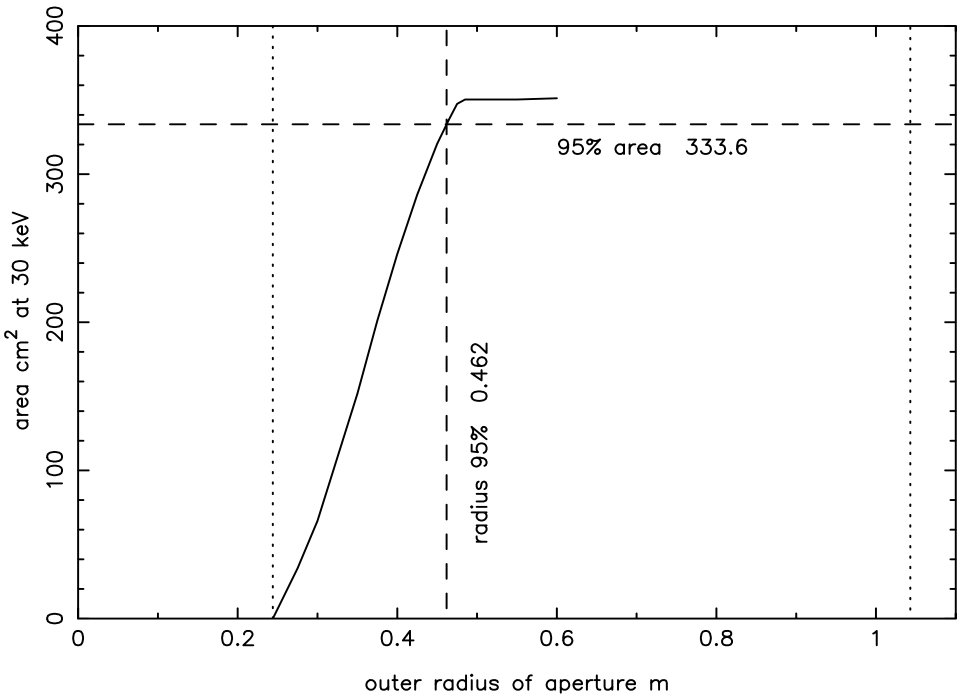
You do need support structure!



If support obstruction is 31% then can achieve 1 m^2 at 6.4 keV.

Baseline design requires support obstruction of 55% which is conservative. This gives 0.65 m^2 at 6.4 keV.

Similar story for 30 keV



Need multilayer coating on the inner shells.

An obscuration factor of 55% will give 185 cm^2 at 30 keV.

The CDF run 4th Feb → 16th Mar 2009 will revisit the area problem.

Preliminary IXO pointing and optical bench stability requirements

Preliminary image quality error budget (HEW on-axis at 1.25 keV):

- Mirror module perf. under operation environment: 4.30 arcsec
  - Optical design (conical approx.~ 3 arcsec)
  - Mirror figuring errors:
  - Mirror mid-frequencies errors & surface roughness:
  - Mirror plate alignment/confocality:
- Mirror assembly system errors: 1.20 arcsec
  - Assembly and integration
  - 1 g release
  - Thermal environment
  - Other (e.g. moisture release)
- S/C pointing and optical bench distortions: 2.00 arcsec
  - Events relative lateral measurement accuracy
  - Absolute longitudinal displacement errors
- Margin: (including PSF sampling/detector pixel size) 1.00 arcsec

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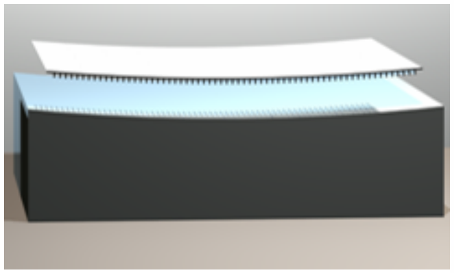
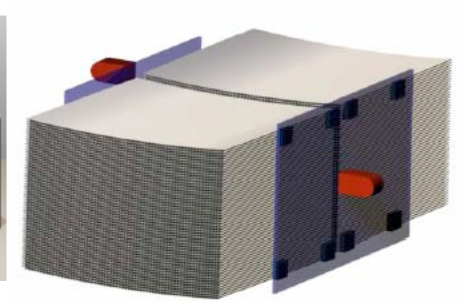
Total (assuming RSS summation): 5.00 arcsec

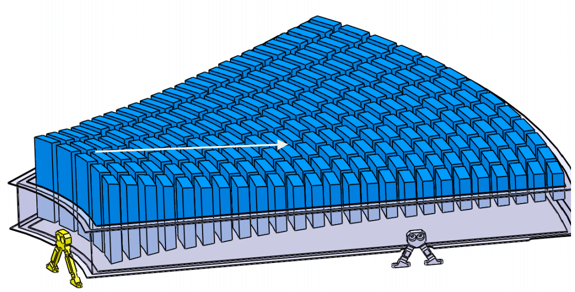
We need mirror modules with slightly better than 5 arc sec HEW to meet specification.

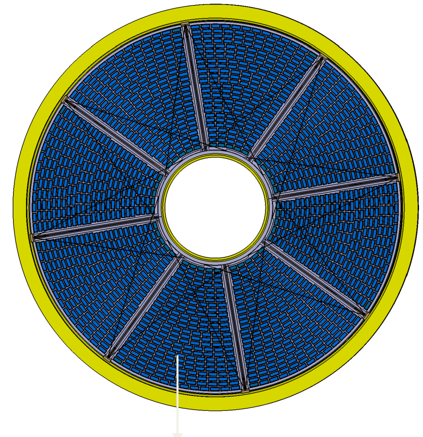
Si Pore Optic based IXO mirror assembly

Hierarchical elements







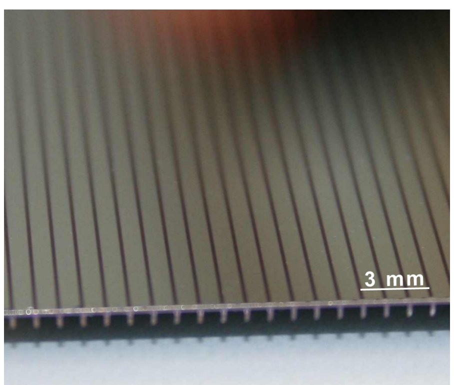


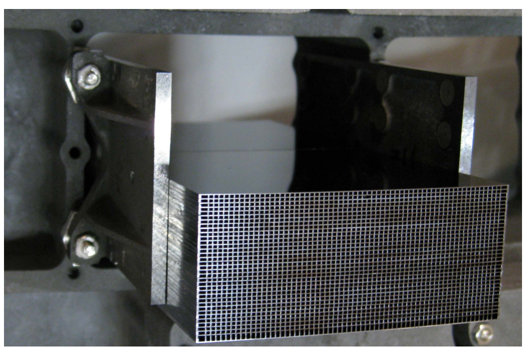
Mirror plates and stacks

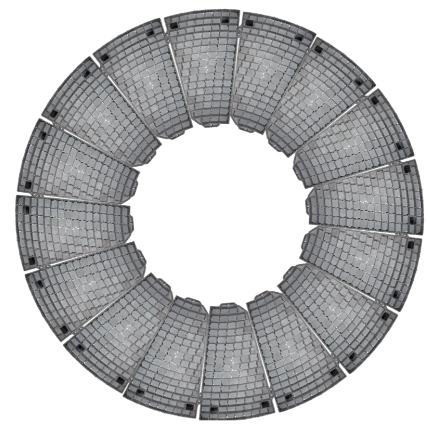
Mirror modules

Petals

Optical bench







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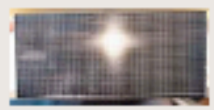
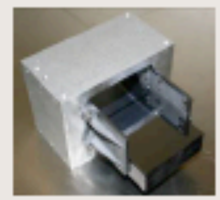
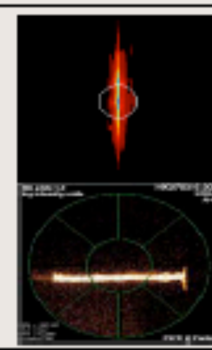
IXO Optics – Development & Production

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

Marco Biejersbergen, Max Colon, Marcus Bavdaz

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Stack production (1/9)

- Stacking robot 2007

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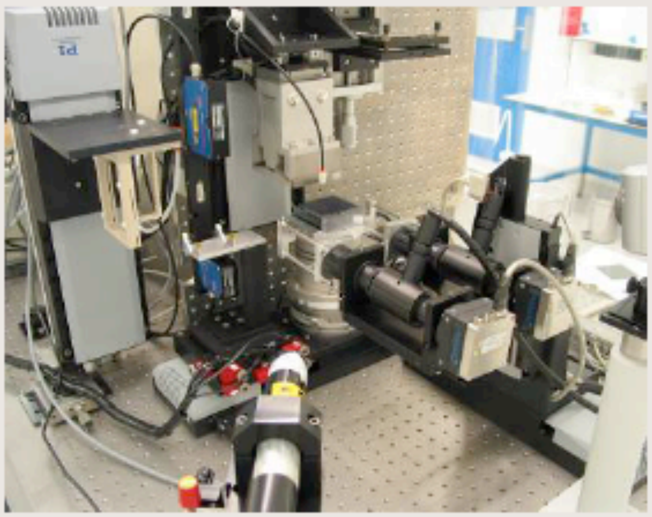
Stack production (2/9)

- Stacking robot, 3^{rd} generation
  - Table top system, fully automated and remote controlled
  - Installed in cleanroom inside class 100 (10) tent
  - Based on a combination of standard semicon tools and newly developed units



Started operation 19^{th} December 2008

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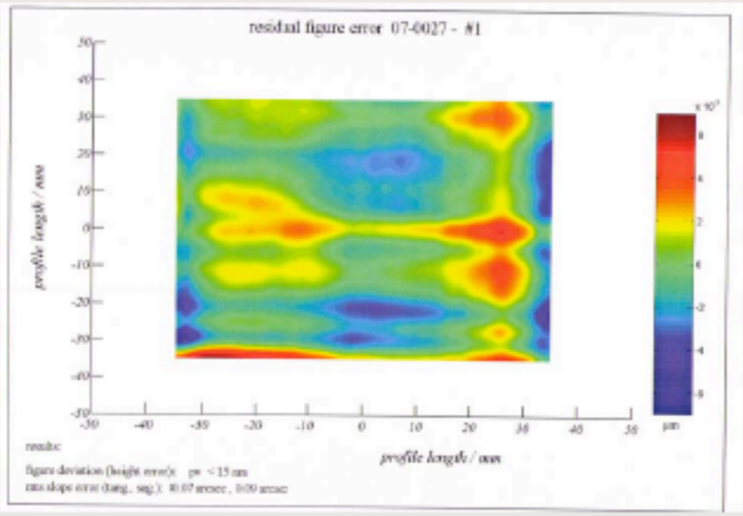
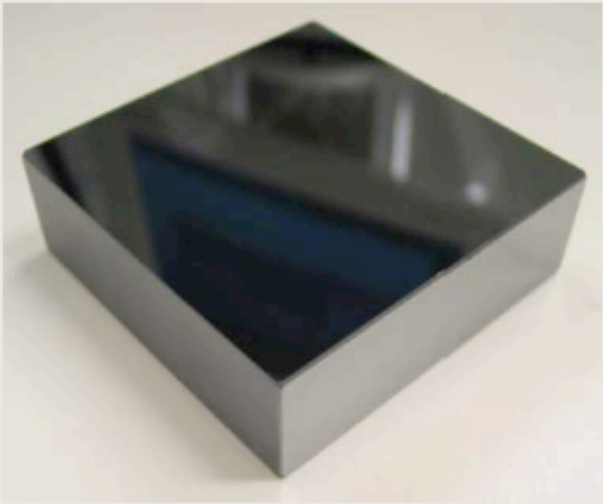
Stack production (3/9)

- Cylindrical mandrels from Zeiss
  - 0.1" rms residual error
  - Only figure (not roughness) important
  - need only 2 mandrels per ring (64 for IXO, not expensive)
  - Investigating now conical mandrels and double curvature





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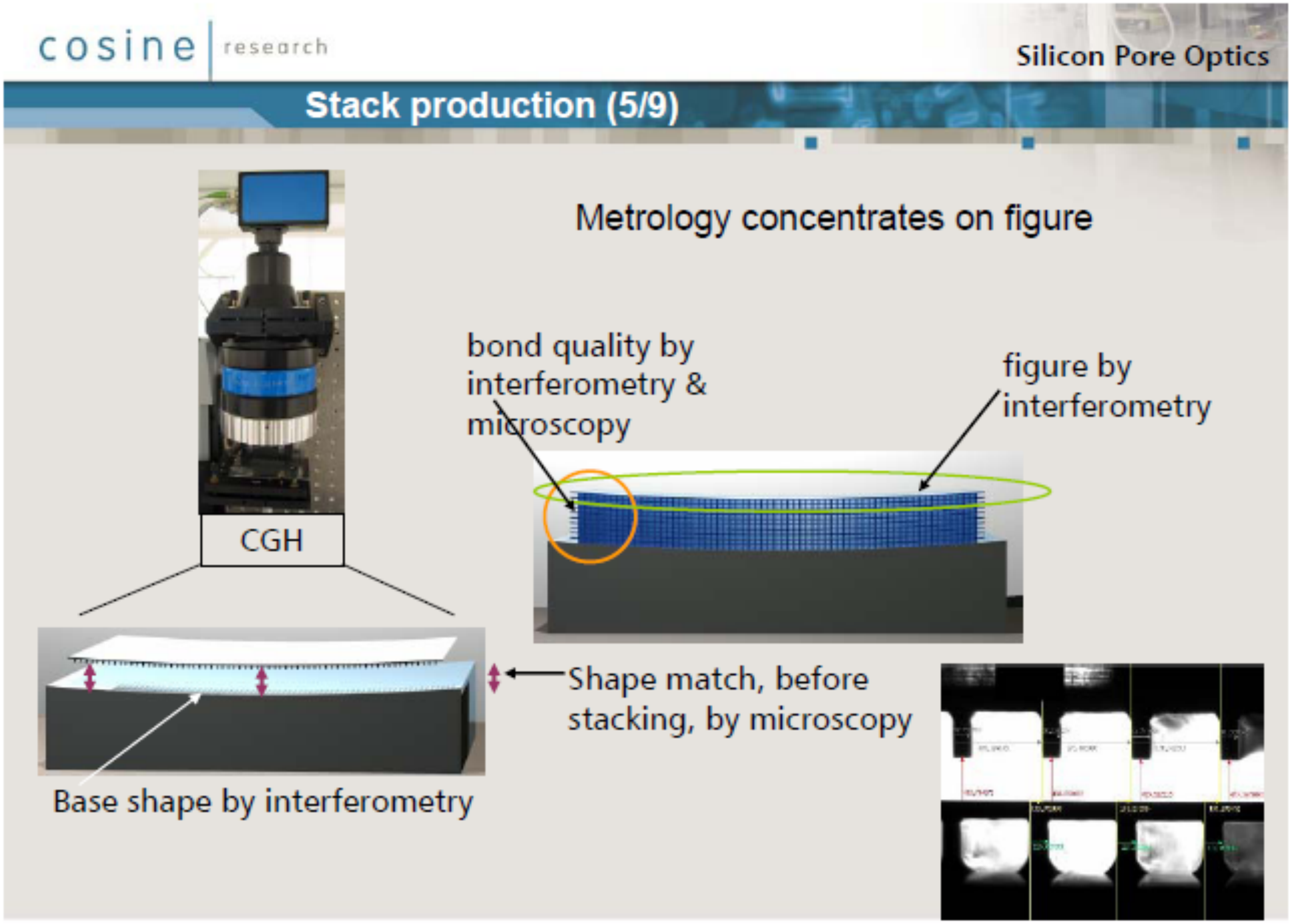
Stack production (4/9)

- Stacking metrology in place
  - Metrology loop to X-ray data closed
- Particle measurement
  - custom particle detection system
  - calibration ongoing, special contaminated wafers will be ordered
- Plate-Plate alignment
  - microscopic / image analysis (< 5 μm accuracy)
  - force sensors (15 sensors / cm^2, 1 mN resolution)
  - front / back radii adjustable from 1900 to 2025 mm with 0.03 μm accuracy)
  - Tip/tilt 0.3 μrad resolution
- Figure
  - Twyman Green interferometer with CGH cylindrical nulling lens (FoV 100 mm)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Stack production (5/9)
Metrology concentrates on figure
bond quality by interferometry & microscopy
figure by interferometry
CGH
Shape match, before stacking, by microscopy
Base shape by interferometry

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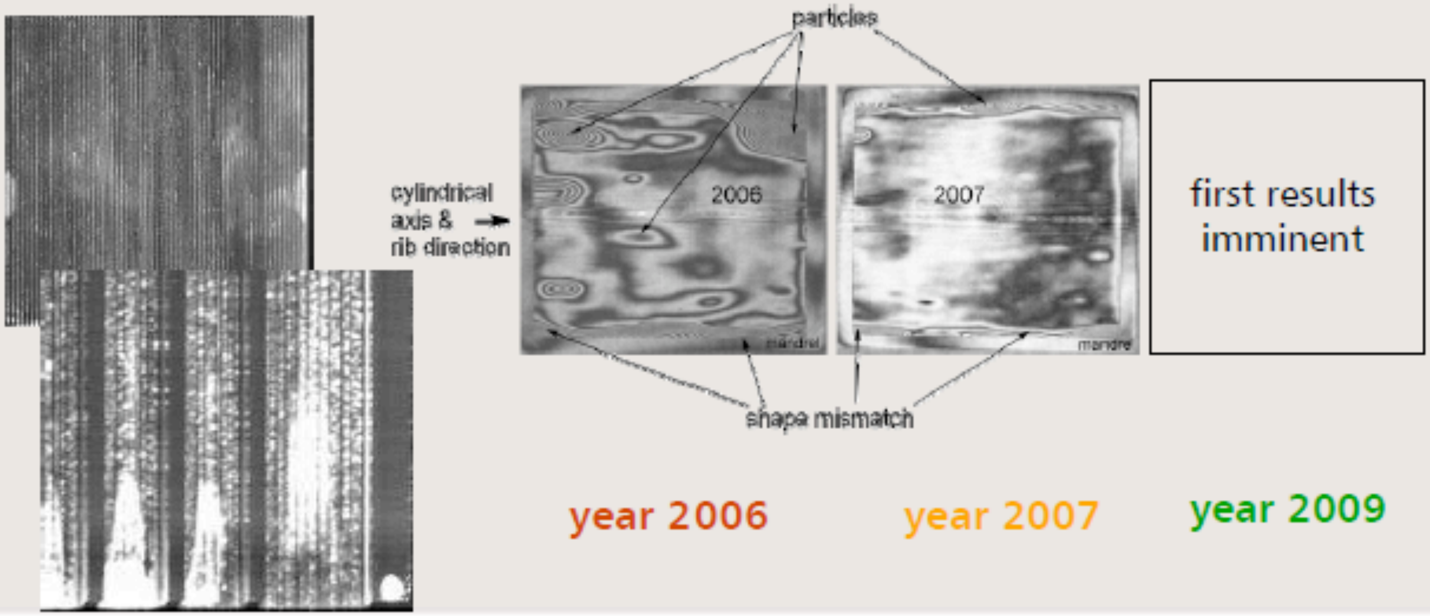
Stack production (6/9)

- Particle detection with custom system based on scattering
  - Difficult is detection on ribbed side
  - Current requirement (particles < 1 µm)
  - Final goal < 100 nm (elastic deformation of silicon)



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Stack production (8/9)

- Pull tests in preparation (Q1 2009)
  - confirm bond strength values
  - study bond strength as function of process parameters
  - Note: so far (3 years) no bonded stack came apart, 2 modules mounted in petal since 2 years
- Environmental tests in preparation (Q2 2010)
  - Vibration of stacks
    - ➢ **Need to perfect stacking, stacks still quite costly**
    - ➢ **So far no indication of problems:**
      - Transporting stacks by courier and/or hand carrying
      - Mounting and dismounting at BESSY, PANTER and at KT
  - Thermally cycled one HPO
    - ➢ **100 h @ 200 deg C**
    - ➢ **No measurable degradation of figure of top surface**

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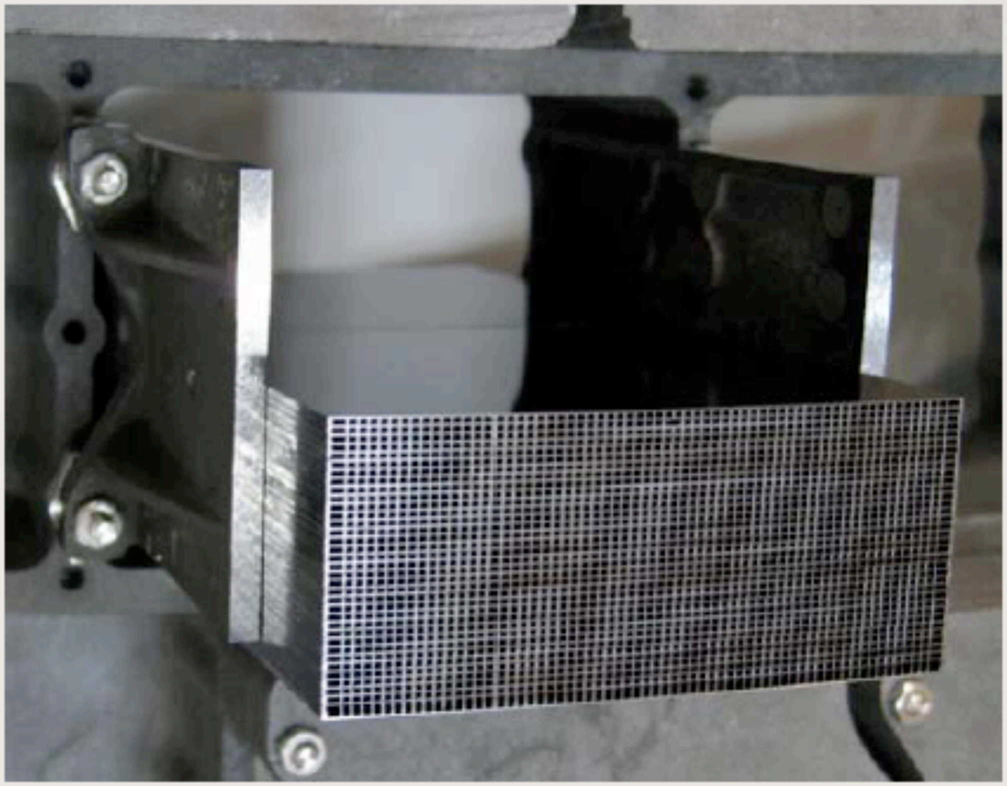
Module production (8/8)



Module, mounted in petal prior to PANTER testing

This stack has not got the full compliment of Si plates

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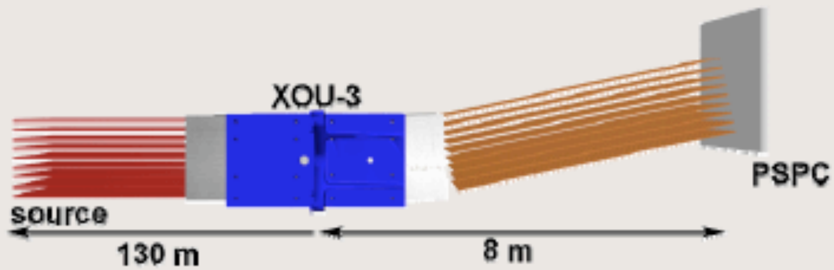
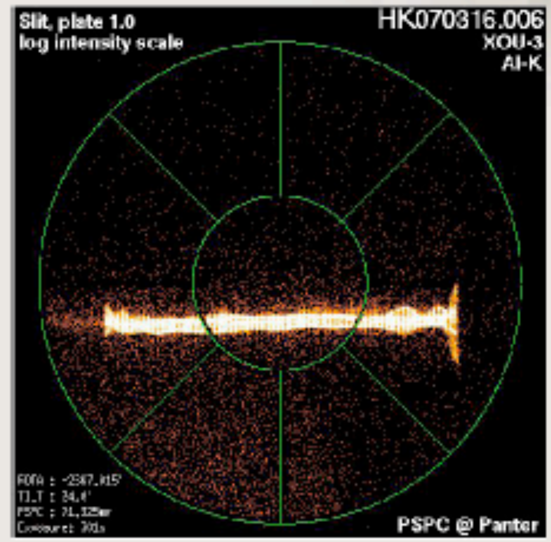
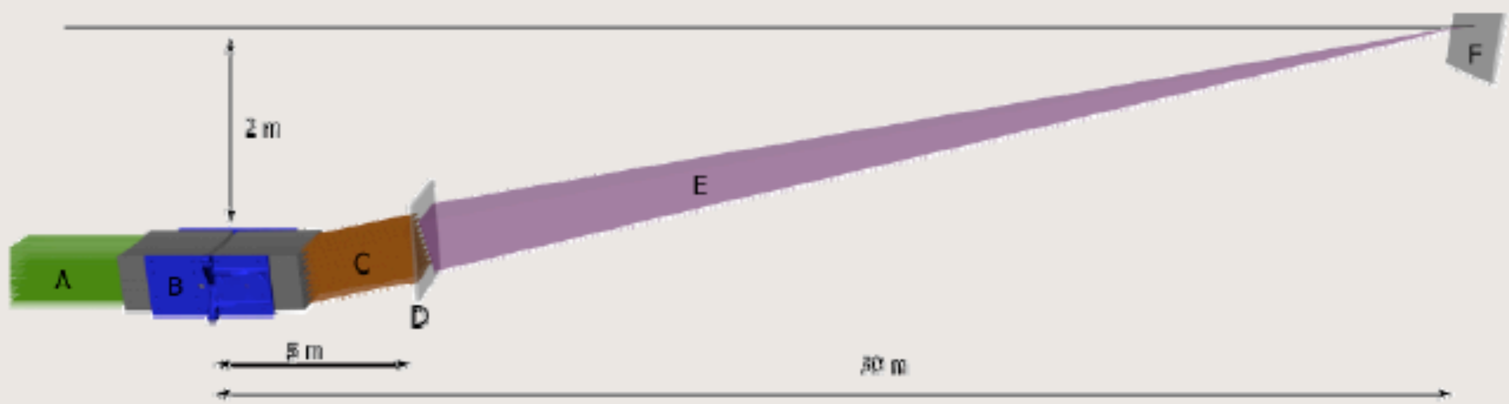
Mirror module testing

- PANTER full beam (divergent)





- BESSY pencil (50μm) beam



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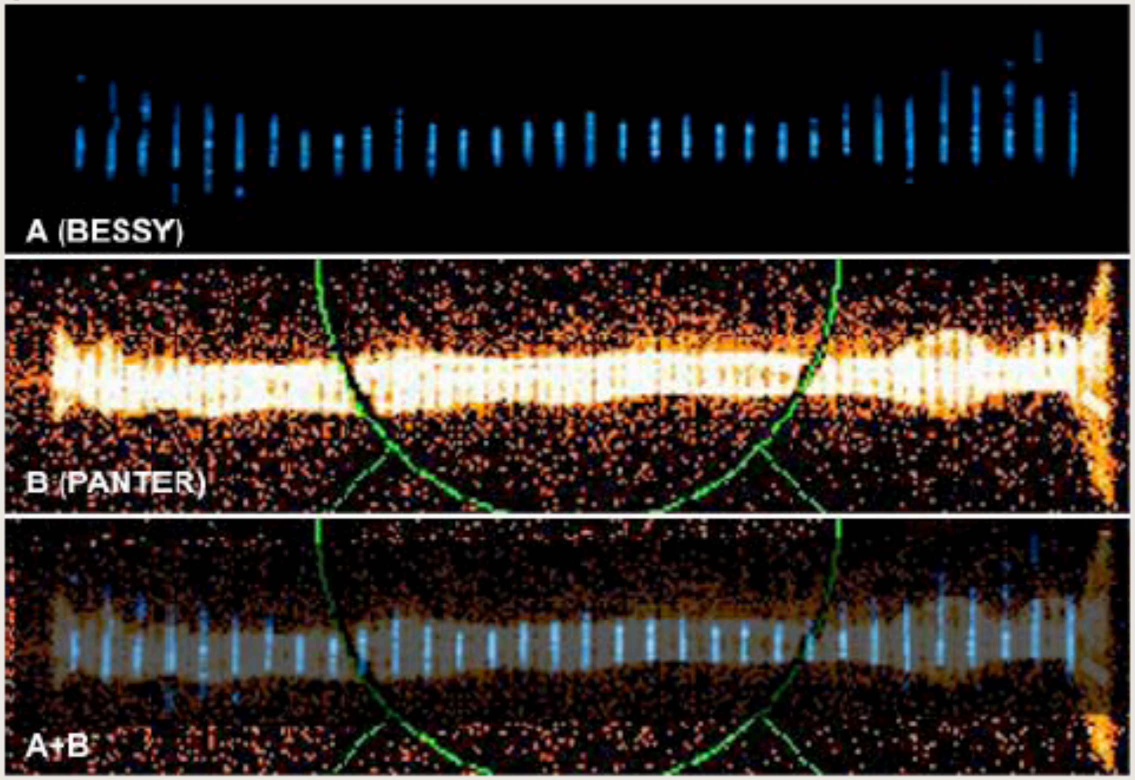
Mirror module testing

- Repeated PANTER measurements at BESSY



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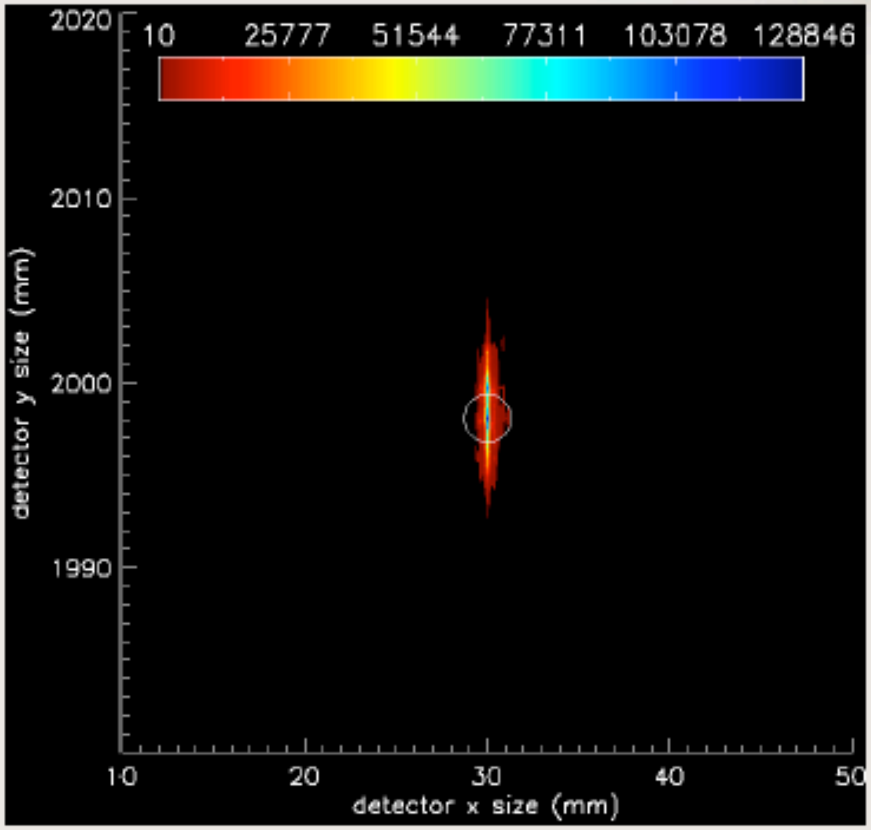
Mirror module testing

- HEW 17" @ 50 m
  - double reflection
  - mounted optics
  - absolute
  - no subtraction
- Plates 1-4
  - full width
  - A_{col} = 1.25 cm^2



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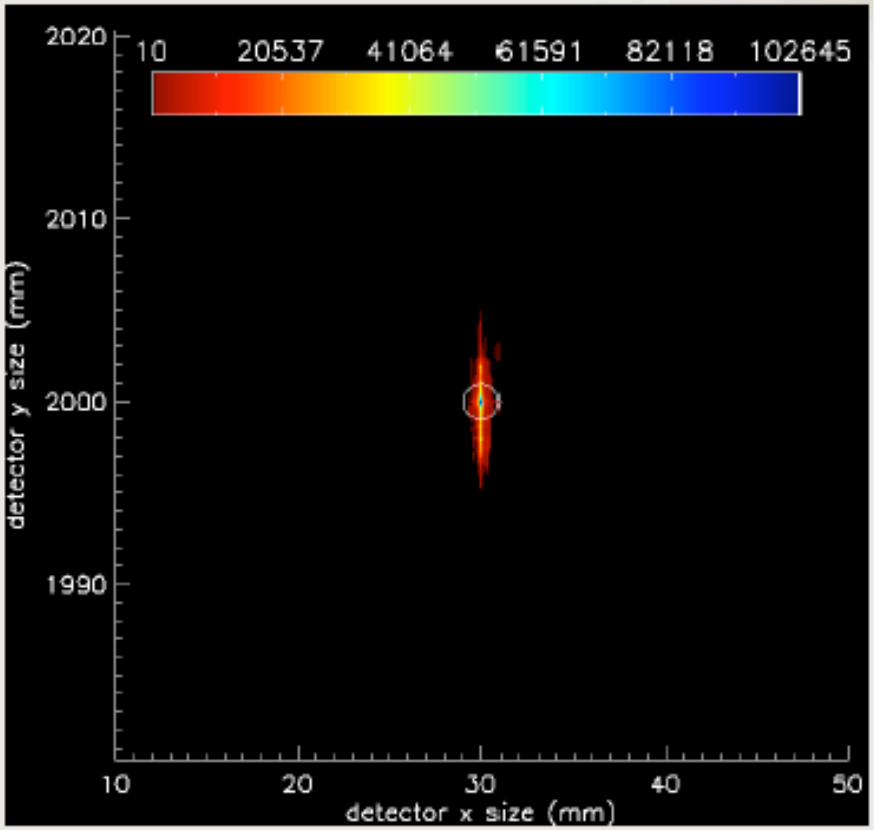
Mirror module testing

- Remove known particle locations
- Select first two plates (larger bonded area)
- HEW 8" @ 50 m
  - double reflection
  - mounted optics
  - absolute
  - no subtraction
- Plates 1-2
  - full width
  - $A_{col} = 0.6\ cm^2$



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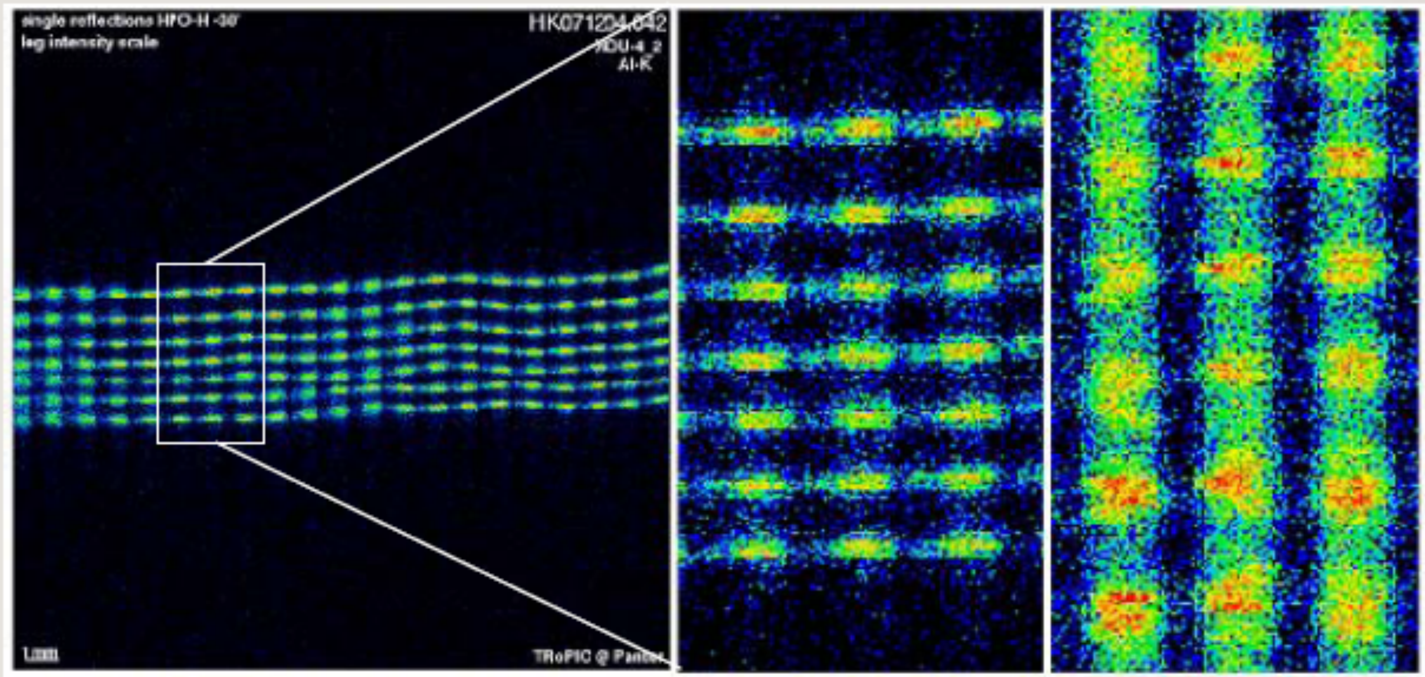
Mirror module testing

Expected spacing 713.0 µm, measured spacing 711.5 µm



single reflection | double reflection

Have built and demonstrated first fully focussing XOU

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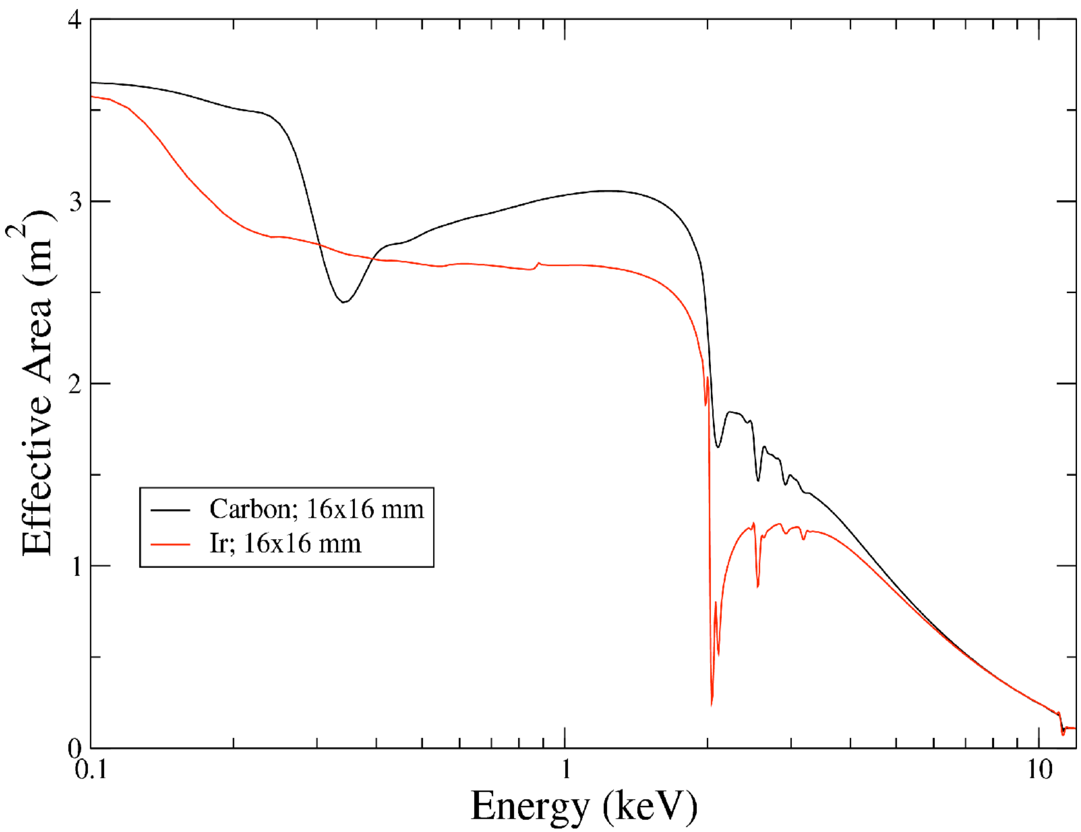
Conclusions

- Silicon Pore optics are close to TRL 4
  - Plates are mass produced by industry
  - Have mirror modules and a mounting method
  - Coating inside pores (Ir+C)
  - We are testing mounted optics in flight configuration
- Mass production of modules ramping up
  - industrial consortia are forming
  - co-locate plate production, coating and stacking in semicon fab
    - industrial stacking robot fits onto one optical table
    - production of one coagted stack (45 plates) every 2 hours possible
- ESA funding for technology development is in place
  - ruggedization
  - figure improvement
  - industrialisation

  all being addressed 2009-2010

IXO mirror assembly: performance estimate baseline CDF study



Without C overcoating:

Aeff (1.25 keV) ~ 2.6 m^2

Aeff (6.00 keV) ~ 0.65 m^2

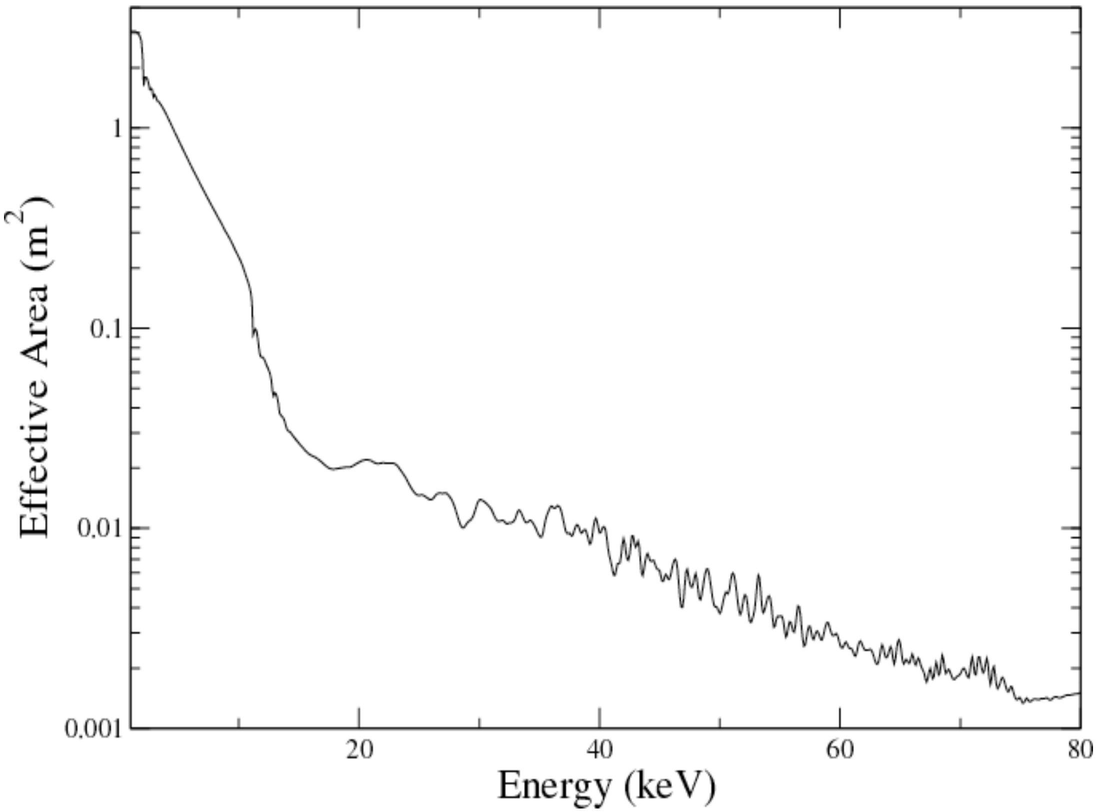
With 90 Angstrom C overcoating:

Aeff (1.25 keV) ~ 3.0 m^2

Aeff (6.00 keV) ~ 0.65 m^2

To achieve the 3m² Aeff at 1.25 keV requirements, the mirror modules shall be covered with a C overcoating

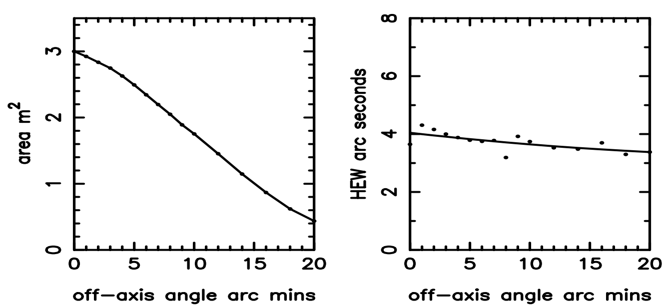
IXO mirror assembly: performance estimate baseline CDF study



With JAXA/ISAS multilayer design (courtesy H. Kunieda):

Aeff (30 keV) ~ 150 cm^2

Off-axis response of Si Pore Optics



Ray tracing predictions – includes conical approximation and a small figure error

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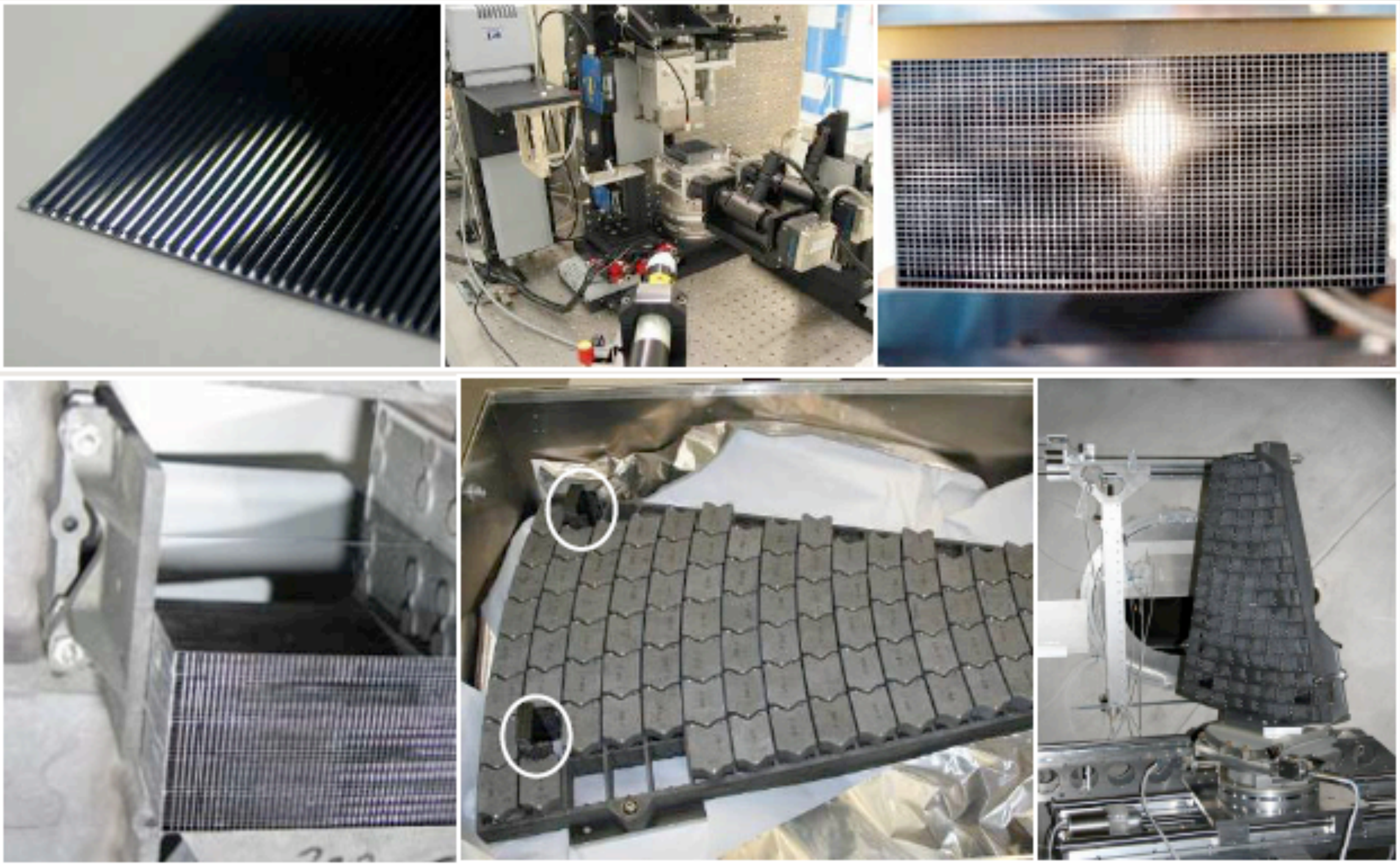

Issues/Actions/Recommendations IXO TWG January 2009 Boston

- Extension baffle/skirt evaluation/optimization – stray light
- Front baffle for mirror assembly – stray light transmitted through mirror system
- Grating spectrometer – specify sub-aperture PSF needed to achieve high spectral resolution
- Upgrade of test/calibration facilities and use of BESSY, SPring-8…
- Repeat the optical design for both Si Pore and slumped glass technologies using common criteria/data/software
- Full comparison/trade-off of Si Pore vs. slumped glass technologies
- Major push to demonstrate a mirror module with ~5 arc seconds HEW (Si HPO or ~3 nested slumped glass pairs)
- Construct a full error budget for the angular resolution – as far as possible common to both mirror technologies

Mirror Baffle

- Preliminary studies have been done
  - Si pore optics can incorporate a baffle integral to the front (parabola) plates
  - This solution is not possible for the inner most (small radii) modules
  - There will be a residual enhancement of diffuse sky background maybe up to a factor of 2 – needs a dedicated study for both the Si pore and slumped glass technologies

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Mirror module testing future

- Both BESSY and PANTER will be upgraded 2009/2010
  - Measure in focal plane of optics
  - BESSY change energy from 3 keV to 1 keV
    - larger grazing incidence angle
    - 20 m tube can be accomodated
  - PANTER upgrade more complicated
    - requires synchronization with eRosita and Symbol-X activities