International X-ray Observatory

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The Path to Mirror Readiness

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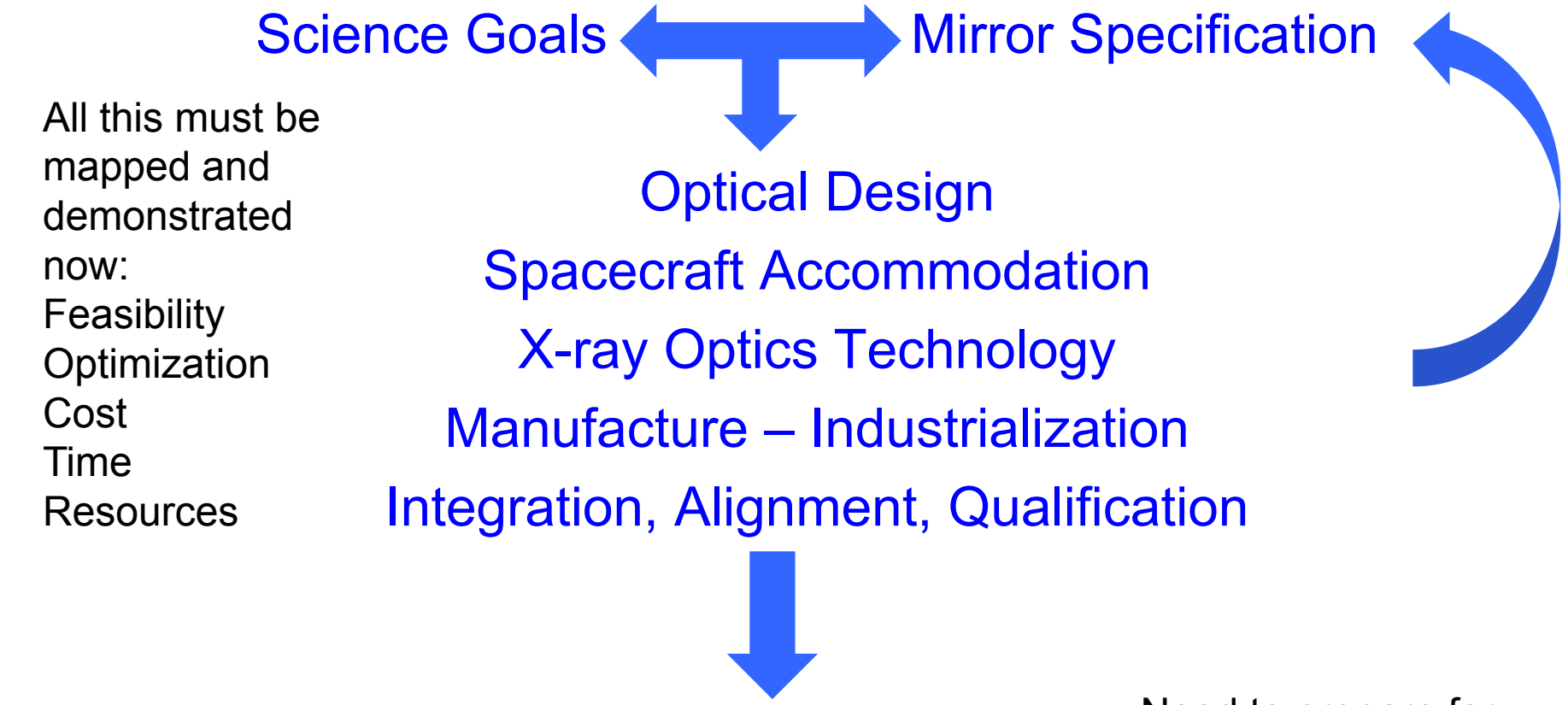
European Chair of the IXO TWG

The Simplistic Route

The Actual Route



All this must be mapped and demonstrated now:
Feasibility
Optimization
Cost
Time
Resources

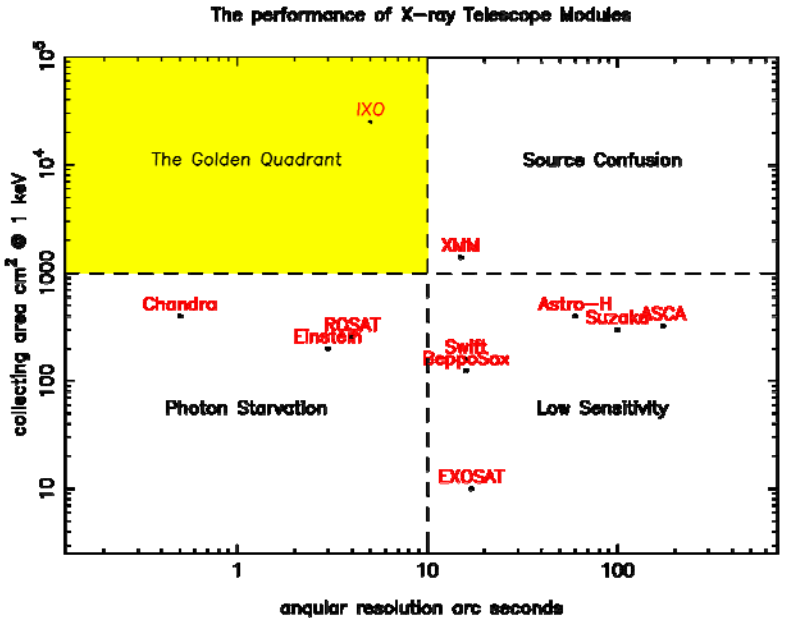
Need to prepare for this in the near future

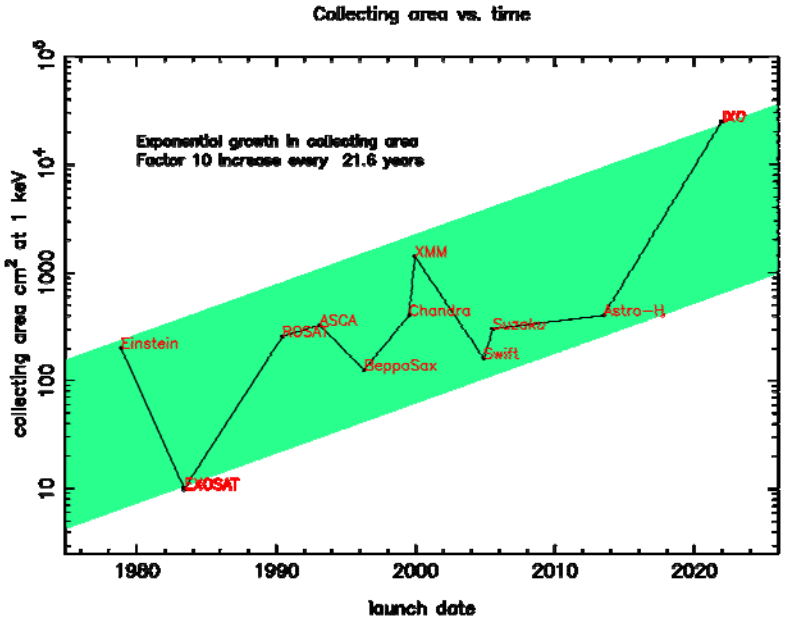
Everything above must be doable and demonstrated
Technology Readiness Level 5+

An Impressive Specification

- Collecting area
  - 2.5 m^2 @ 1.25 keV
  - 0.65 m^2 @ 6 keV
  - 150 cm^2 @ 30 keV
- Angular resolution
  - 5 arc seconds 0.1-7 keV
  - 30 arc seconds 7-30 keV

- Large area - sufficient counts for spectroscopy and temporal analysis of faint sources
- High angular resolution - avoid source confusion of faint sources
- High resolution imaging of extended sources
- Broad energy response 0.1-30 keV





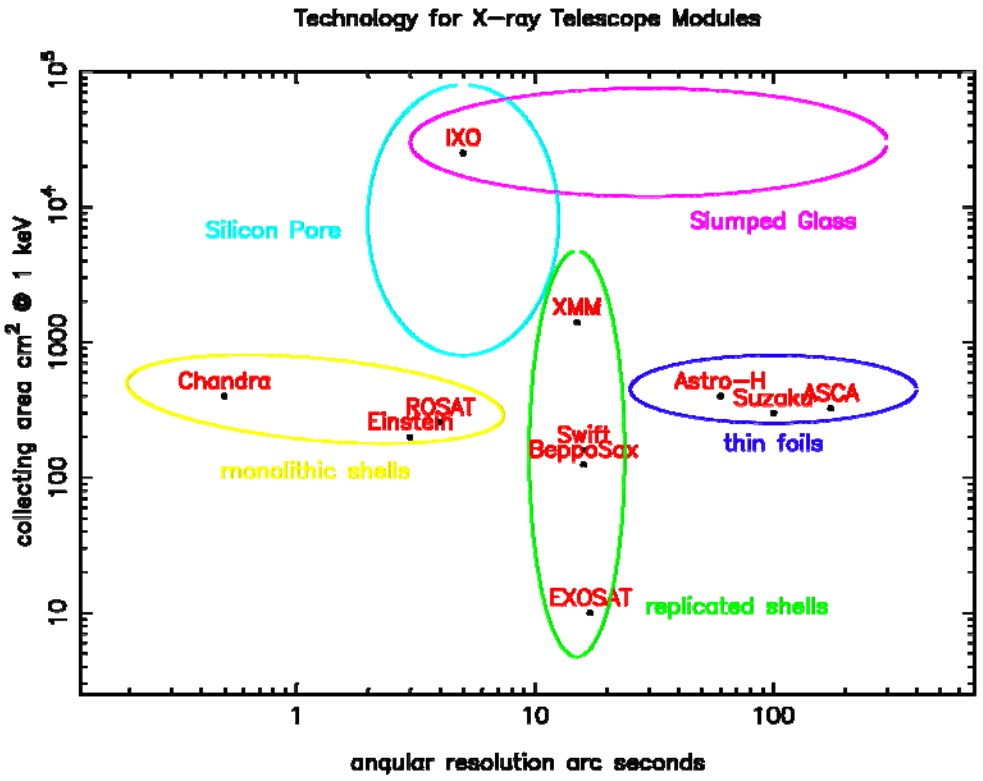
Still very impressive if ~ 1m^2 and ~10 arcsecs

The Technological Challenge

- Wolter Type I geometry – 2 aspheric reflecting surfaces
- Mean grazing angle Θ_g~1 degree
- For a geometric collecting area A require reflecting surface area of ~$2A/\Theta_g$=120A
  - for current spec. need ~300 m^2 – a tennis court 25x12 m^2
- Thin reflecting surface membrane/substrate thickness 150-300 μm for high aperture utilization at grazing incidence
- For low scattering/high efficiency/high angular resolution the polished surface must have roughness ~3 Å rms
- For angular resolution of 5 arc seconds the surface figure on reflecting surface must have gradient errors <2 arc seconds
  - 10 μm for every 1 m along surface
- Iridium coating of outer aperture shells for high reflectivity <10 keV
- Multilayer coating of inner aperture shells for response out to 30 keV

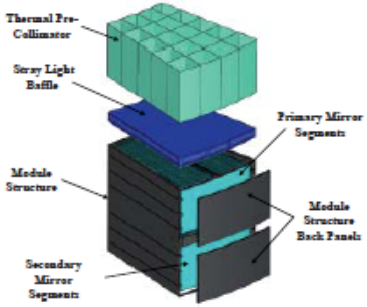
A real challenge BUT we are very close to achieving this

X-ray Optics Technology



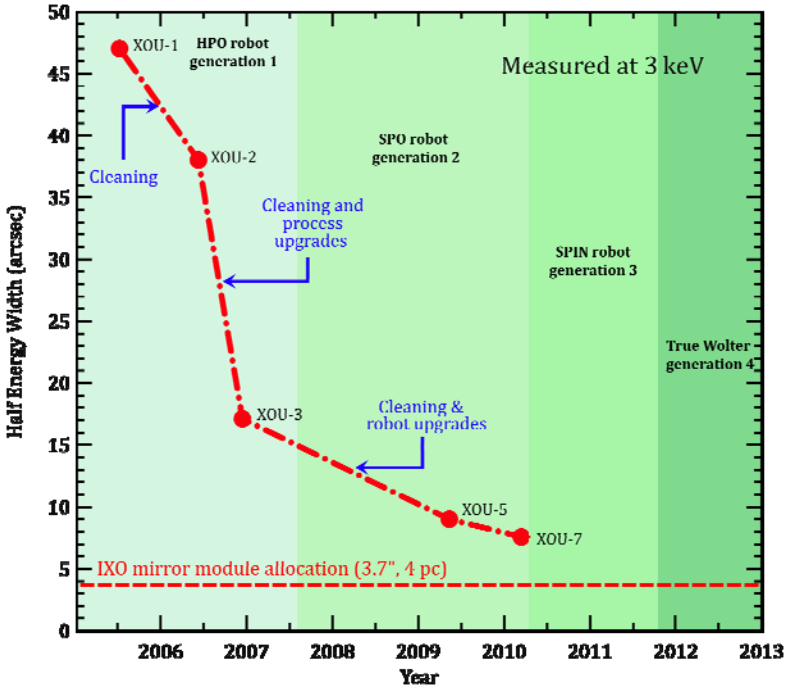
- Aperture diameter 3.8 m
- Mirror mass ~2000 kg
- Focal length 20 m
  - Extendable Optical Bench

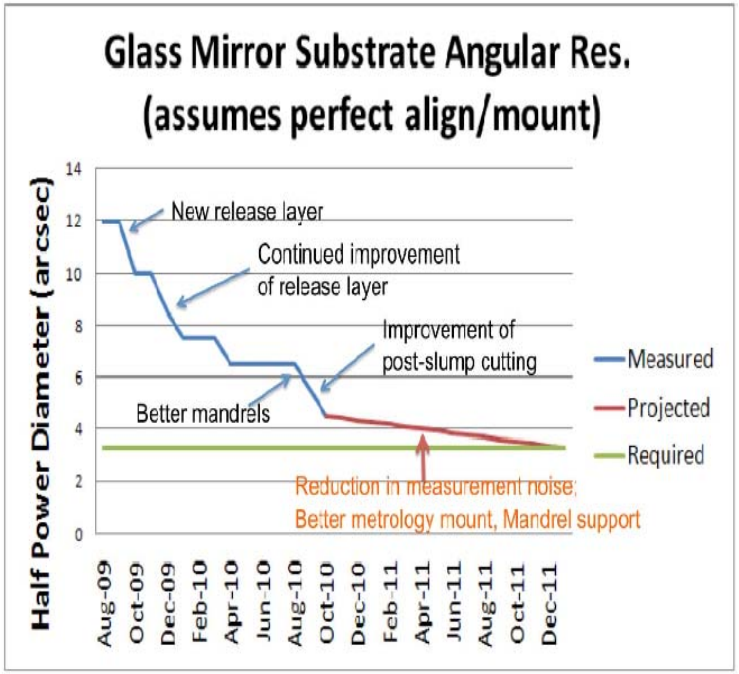
- Silicon Pore Optics
  - Baseline
  - ~180000 Si plates
  - ~2000 HPO modules
- Slumped Glass Optics
  - Backup
  - ~14000 glass segments
  - ~70 sector modules



Progress towards an HEW of 5 arc secs

- R&D programs for SPO and SGO still running
- Both technologies meet the collecting area specification now
- Both can achieve an angular resolution of ≤10 arc secs
- Both have every chance of meeting the 5 arc secs spec.



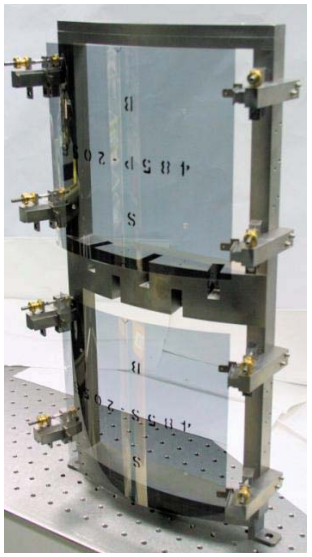


Integration and alignment of many shells

- Integration and alignment of many shells are inherent coupled in the way the SPO stacks are made
- A complete IXO Spec. SPO mirror module with two aligned 45 plate stacks has been constructed and measured – ~16 arc seconds HEW (but using Generation II robotic technology)
- The integration of a single Wolter pair and subsequent integration of a stack of pairs into a module are decoupled for the Segmented Glass Optics – additive stacking errors are not expected – best results so far ~9 arc seconds

Two SPO 45 plate stacks at 2 m radius

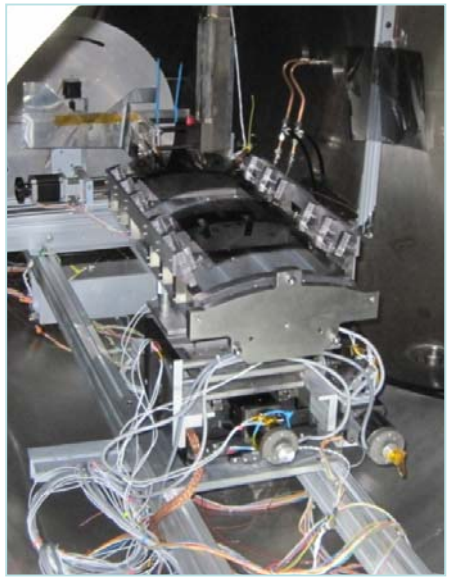
Integrated slumped glass segments



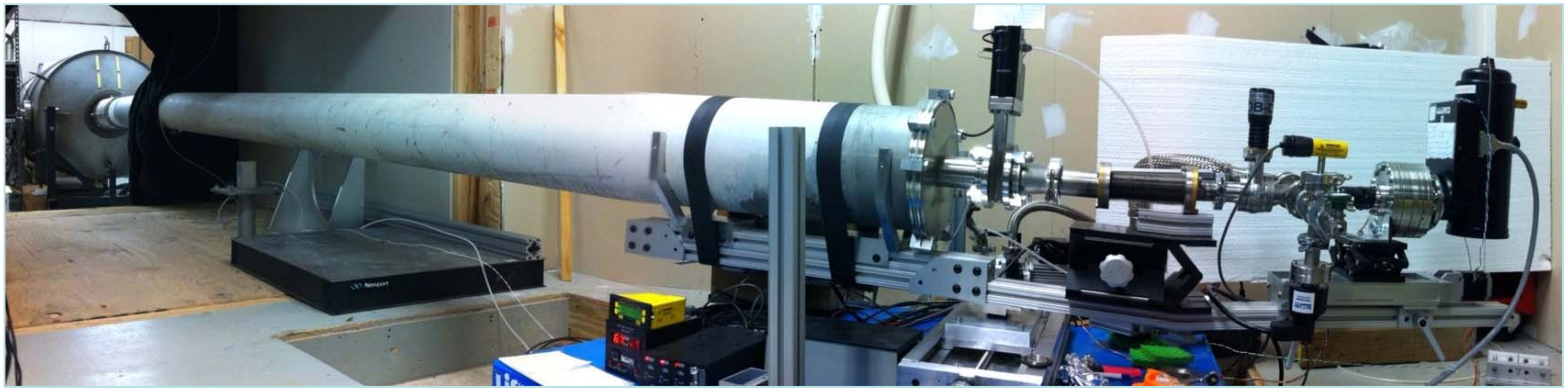
Generation III SPO Stacking Robot

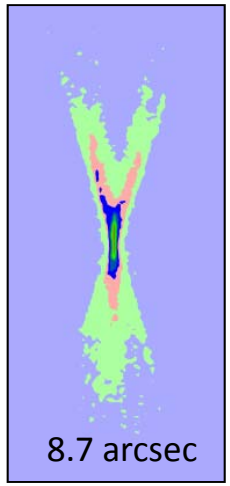
- IXO specifications: r = 0.74, f=20 m
- More flexible and stiffer positioners
- New surface figure metrology, new forming tools
- Commissioning: Q1/2011
- New cleaning wet bench and Marangoni drying system now installed
- Upgraded Particle Detection Scanner

X-Ray Test of Aligned and Permanently Bonded Slumped Glass Mirror Pairs - GSFC

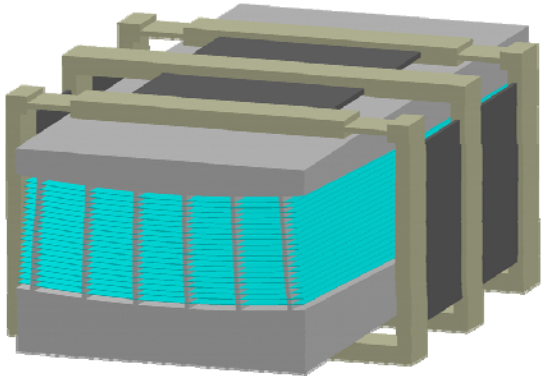


- Aligned and bonded several sets of mirror pairs on flight-like mounts and X-ray tested, achieving better than 10 arcsec HPD images
  - Repeated multiple times
- Latest X-ray measurements of segment show 8.7 arcsec HPD, consistent with optical measurements
- No evidence of reflectivity loss due to X-ray scattering
- Primary source of blur is distortion introduced in permanent bonding step





Current Status of European SGO program - Brera

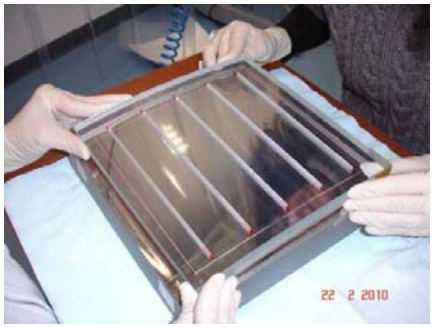


XOU – 20 stacked shells – glass rib spacers

Unit similar to the SPO stacks but larger and glass

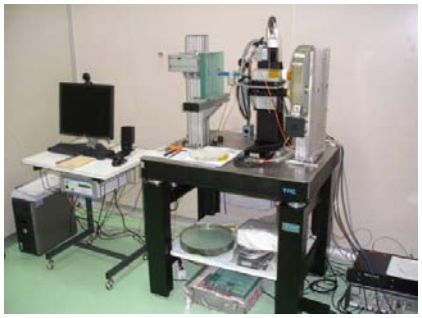
Slumping of the glass plates

Stacking concept based on glass ribs

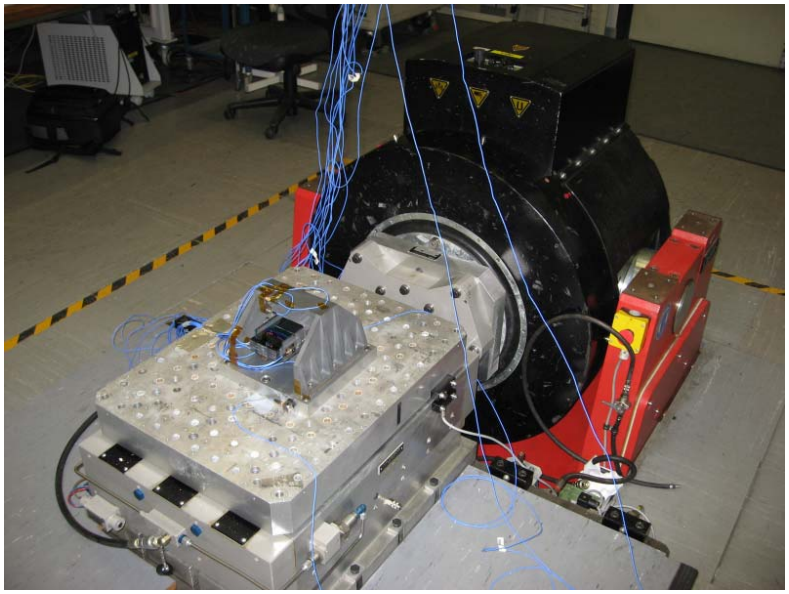


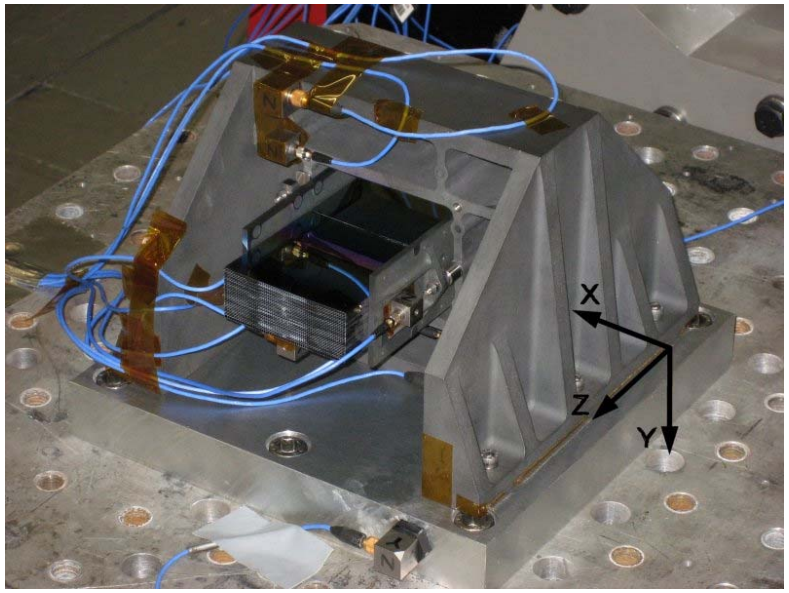
Use of dedicated machine (IMA) for integration

Developed CUP profilometer for characterization



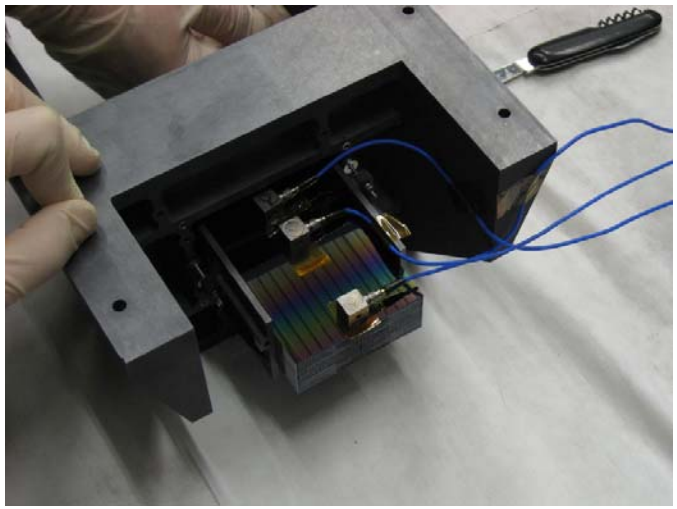
SPO Vibration Testing: Test set-up





Z-axis set up

- Verification of FE modeling
- Quantify structural damping
- Sine sweep and low level random



Acceleration sensors mounted on HPO's

SPO FE model prediction vs. test results

Resonance frequencies of FE model (including CEC bracket) with respect to test:

Mode	f [Hz] Test	f [Hz] FEM	Mode shape
1	811	933	Tx
2	(1088)	1055	Rx not explicitly excited in test
3	1399	1529	Ty and Rz(about fixed pin)

FEM: value for 100% rigid dowel pin-CEC I/F. Real rigidity depends on torque value of dowel pin in CEC (currently 0.3 Nm for M3) .

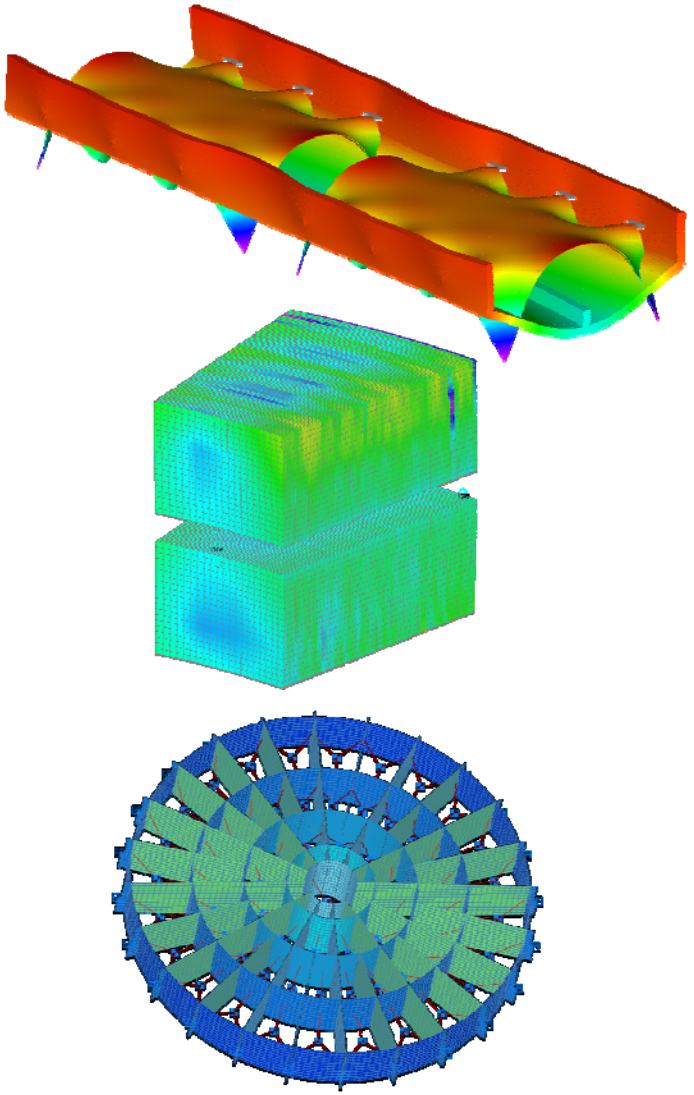
All measured resonances well above requirement (200Hz).

Q-factors assumed in FEM: 25; Q from test: 21

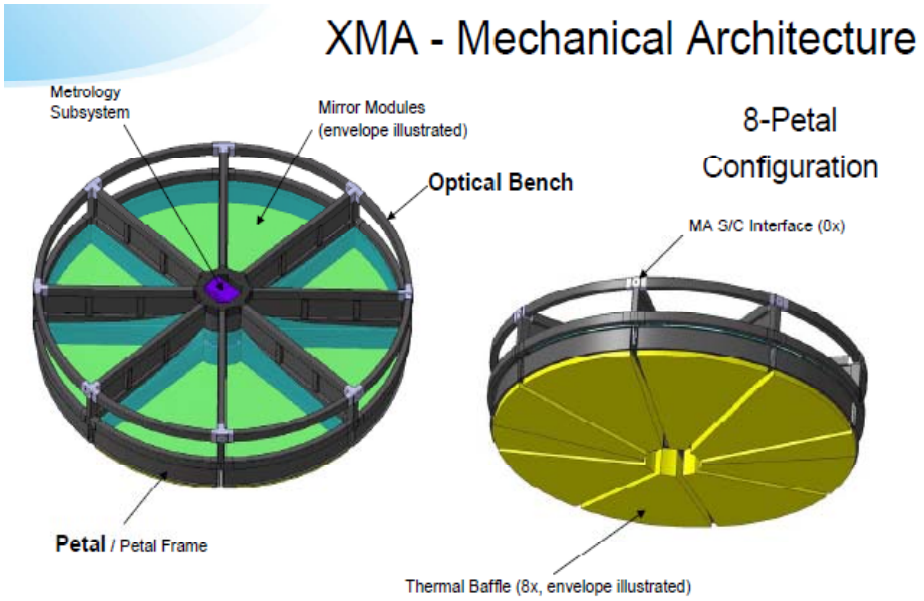
(Less amplification means more margin of safety)

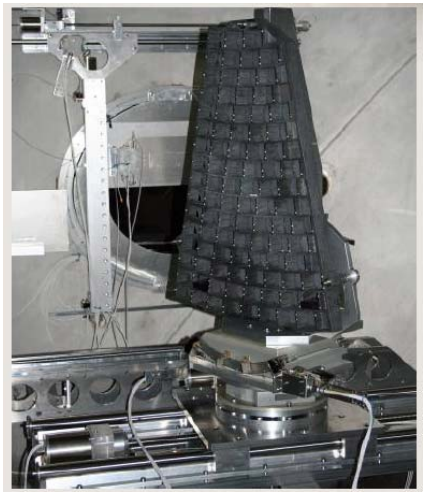
Slumped Glass Module and Mirror Assembly GSFC

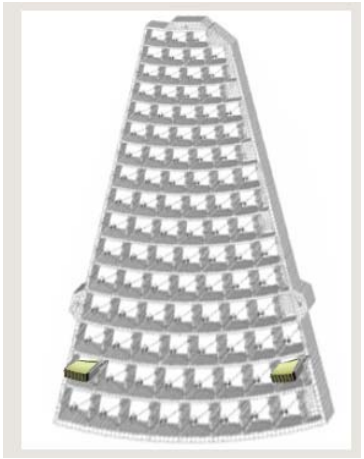
- FEM Work to support X-ray testing and module design
  - Modal analysis
  - Gravity loading
  - Horizontal X-ray test structural optimization
  - Stress analysis
- FMA design to match the eff. Area of SPO
  - Lower modes than ESA SPO study
  - 350 kg lighter
- IXO Spacecraft Coupled Loads Analysis
  - Mass scaled up to maximum lift of Altas V 551
  - Modes raised by structural design improvement
  - Module loads ~8.0g axial 2.0g lateral vs. 18.5g axial 8.5g lateral used for preliminary design
  - All stresses and loads low



SPO Mirror Module Integration







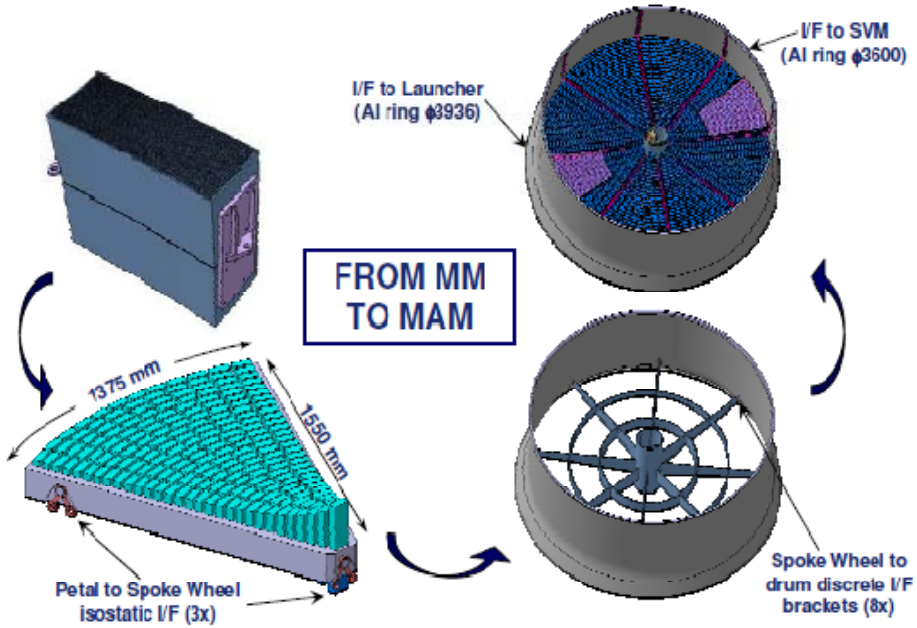
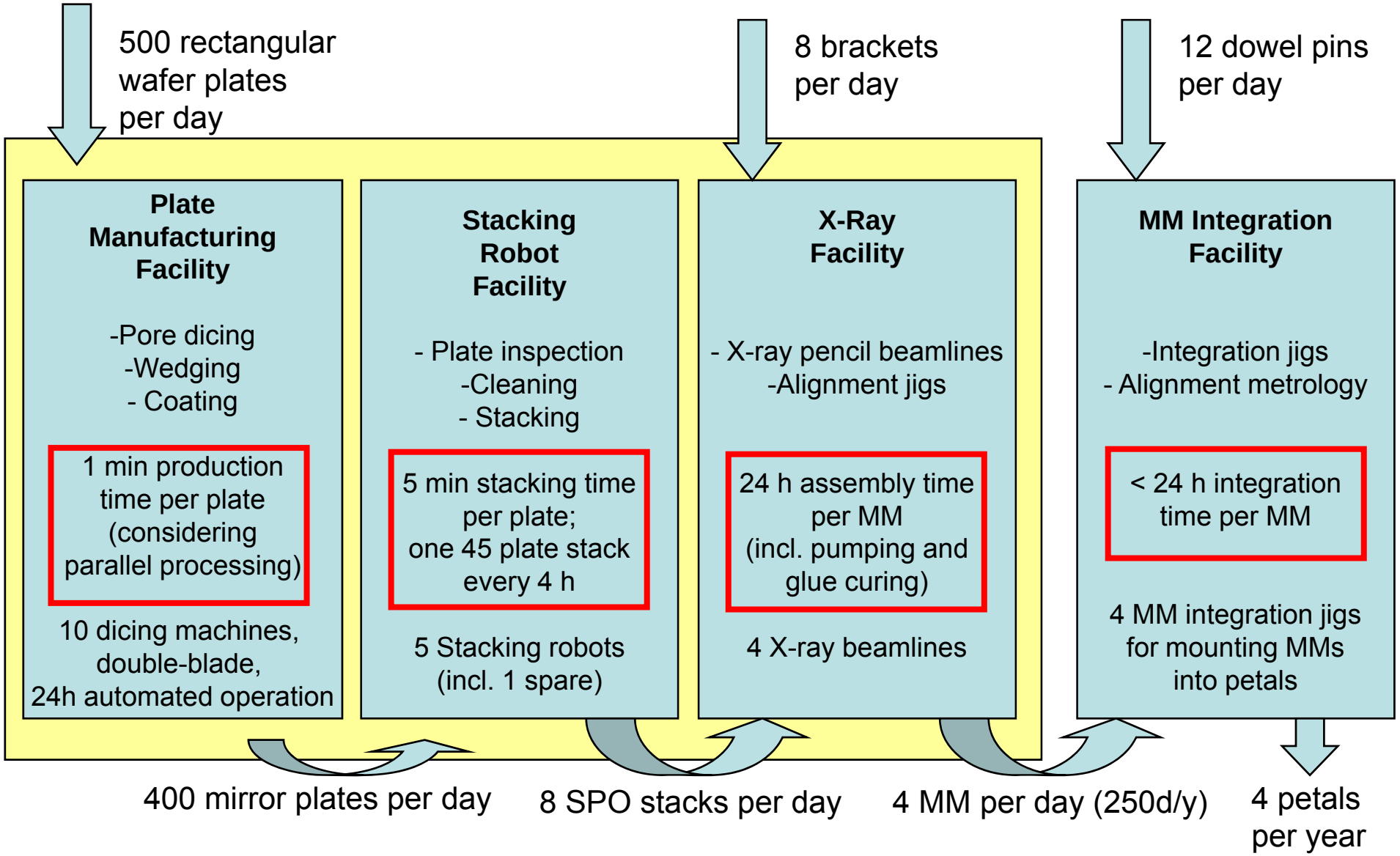


Figure 6.2-1: MAM configuration composition

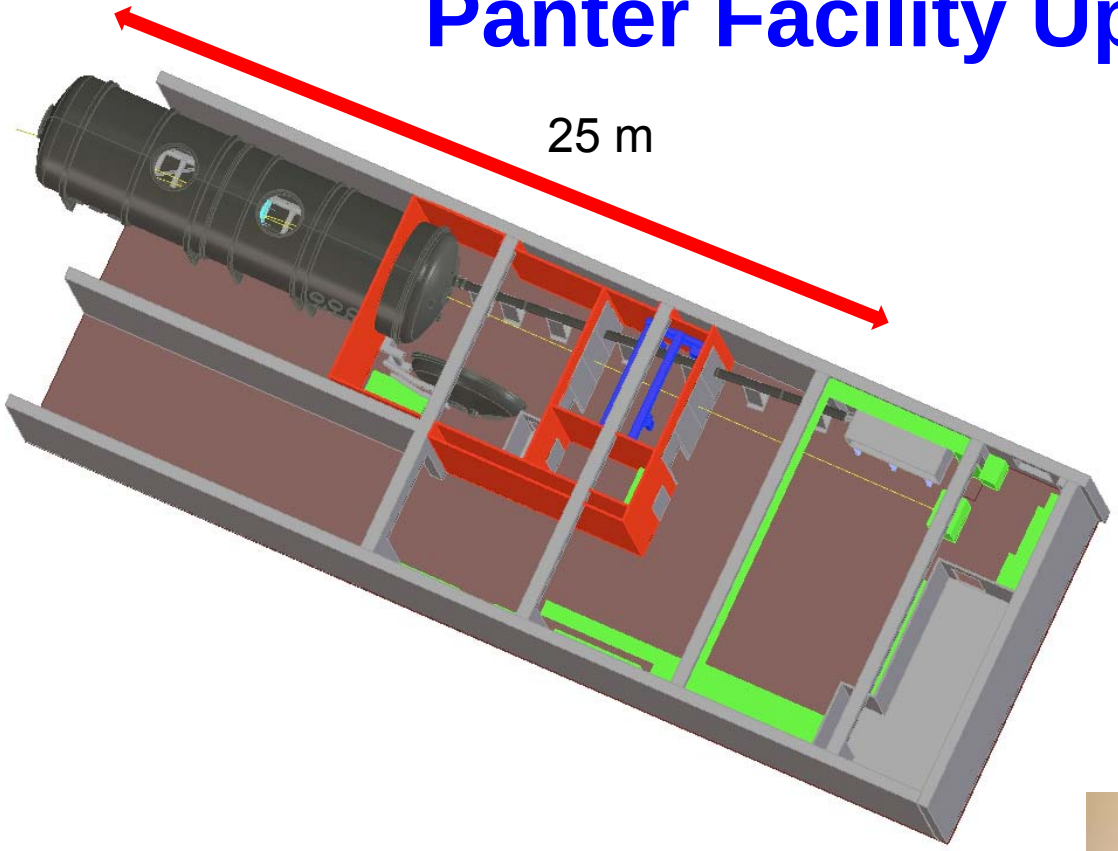
Two independent industrial studies have provided similar and compatible designs for SPO Mirror Module integration

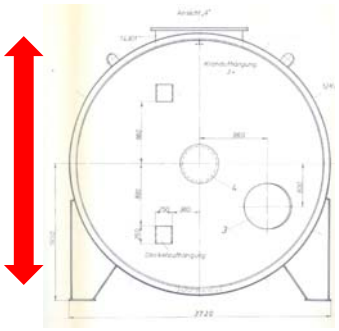
A prototype petal has been manufactured and integrated modules tested in Panter

SPO MM: FM Production flow



Panter Facility Upgrade

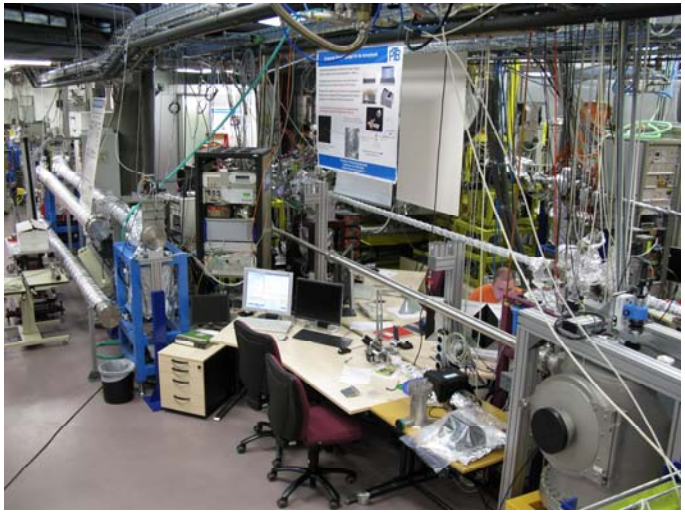


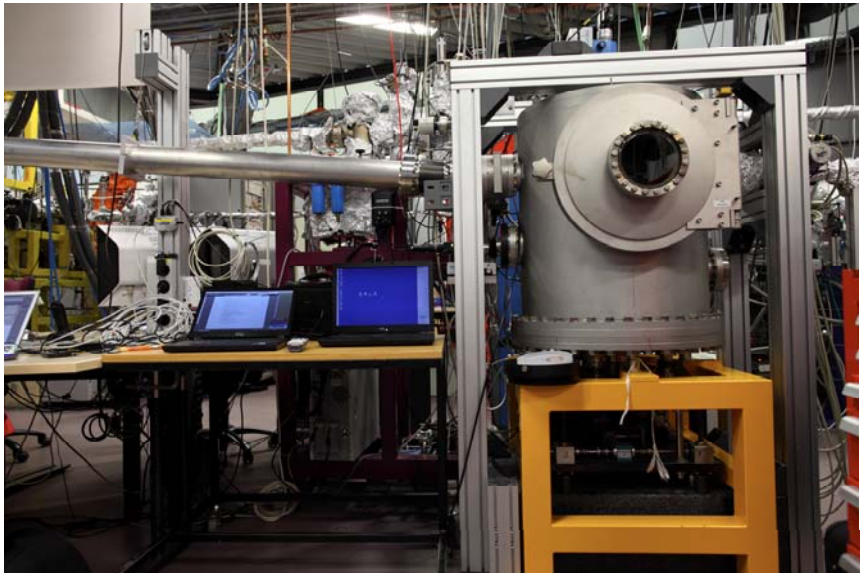


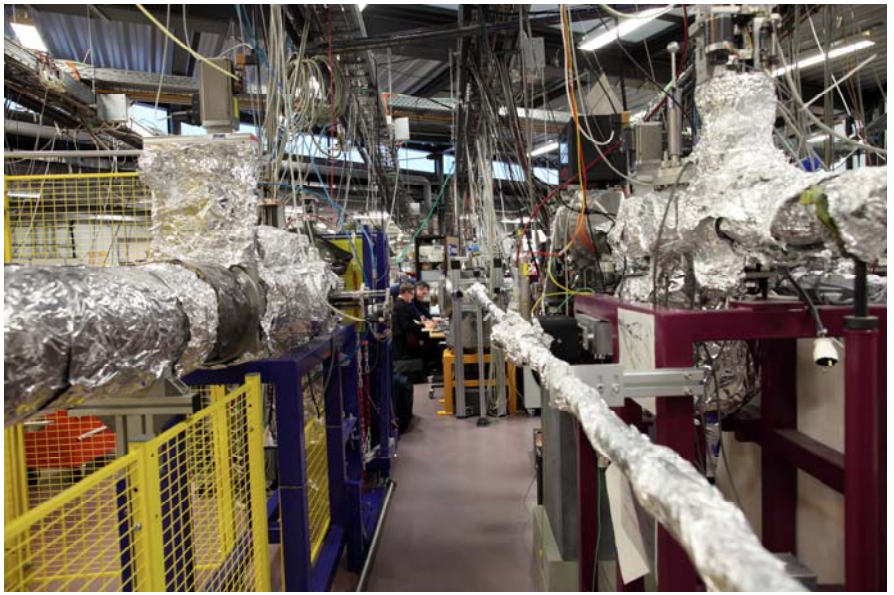
New port on vacuum chamber door
Clean room modifications
Beam line for 20 m focus
Focal plane detector assembly
Automation

Bessy II X-ray facility upgrade

Used for:
- Pencil Beam Testing of SPO stacks
- Alignment of two SPO stacks
- Accurate setting the tilt angle between stacks







Status of Path to IXO Mirror Readiness

- All steps in the production chain for the SPO have been verified – a complete two 45 plate stack SPO module has been manufactured and tested
- Development and testing of the backup Slumped Glass technology is proceeding well in Europe and USA
- Environmental testing of SPO is underway – initial vibration testing results are good. Analysis indicates that the SGO optics are mechanically robust.
- 20 m X-ray testing beam line at BESSY commissioned
- Upgrade of Panter facility underway
- The production flow of the SPO has been looked at in detail
- Both the baseline SPO and backup SGO can achieve ~10 arc sec HEW
- 5 arc sec HEW should be achieved ~end 2012
- Both SPO and SGO can provide the IXO collecting area ~2.5 m^2 at 1 keV