Next Generation X-ray Optics: High Resolution, Light Weight, and Low Cost

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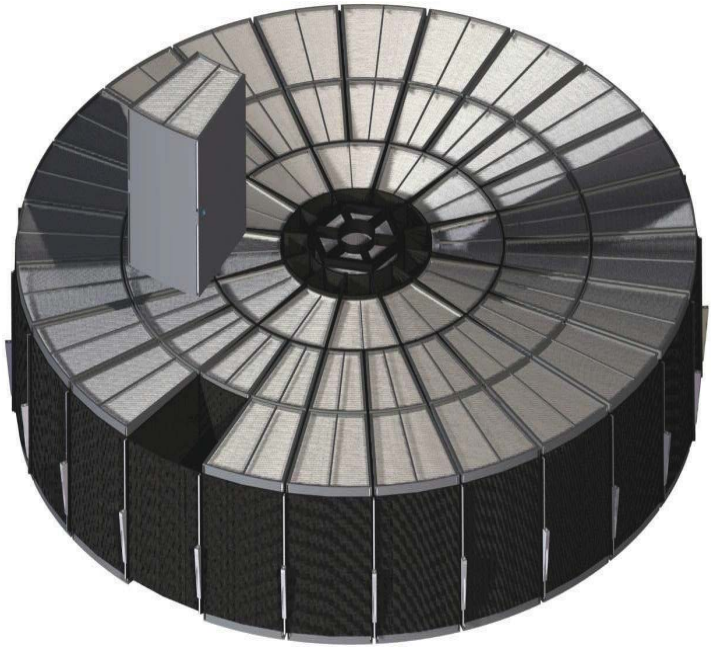
Process of Building a Telescope

~10^4 Mirror Segments

~10^2 Modules
Each containing
~10^2 mirror segments



One or several mirror assemblies

Three Metrics

- Angular resolution
- Effective area (per unit mass)
- Production cost (per unit effective area)
- Field of view (shorter shell length)
- Energy bandwidth (multilayer coating)

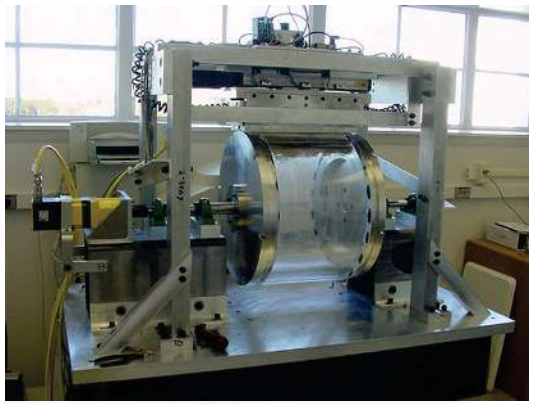
Objectives

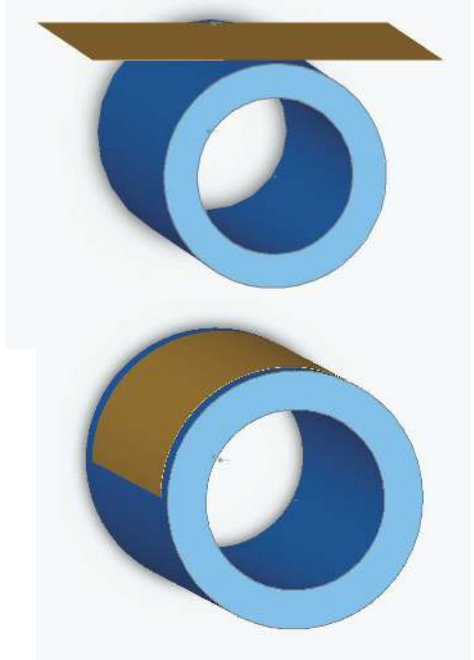
- **Point of departure (2002)**
  - Suzaku's resolution (~120 arcsecs)
  - Suzaku's eff. area per unit mass
  - Suzaku's cost per unit area
- **Near term (2014)**
  - XMM-Newton's resolution (~10 arcsecs)
  - Suzaku's eff. area per unit mass
  - Suzaku's cost per unit area
- **Long term (~2020)**
  - Chandra's resolution (~0.5 arcsecs)
  - Suzaku's eff. area per unit mass
  - Suzaku's cost per unit area

Development History & Future

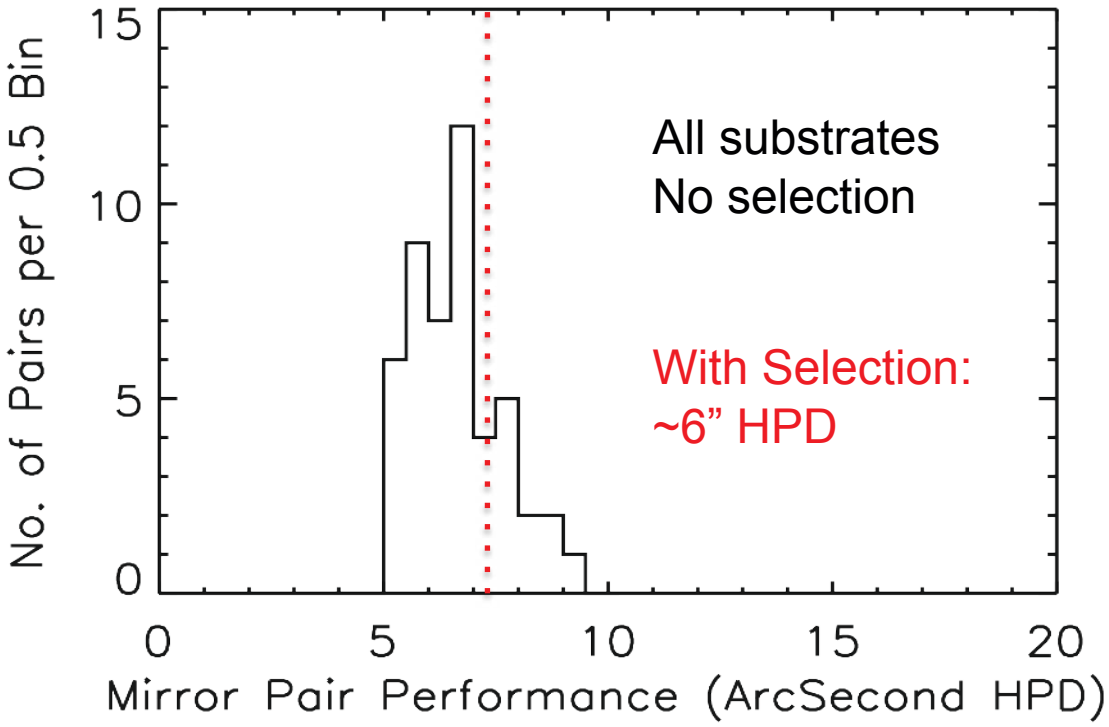
Year	Mirror Segment		Alignment & Bonding		
	Technique	Contribution to HPD (")	Technique	Contribution to Single Pair HPD (")	Contribution to Multiple Pair HPD (")
2002	Slumped glass with epoxy replication	60	Optical Alignment Pathfinder	?	?
2007	Slumped glass	10	Mattress	12	?
2010		8	Smart Bonding	10	?
2012		6	Edge Bonding	8	12
2013	Single Crystal Silicon (Machine & Polish)	~1		?	?
2014		~0.1	?	?	?
2018		~0.1	?	?	?

Glass Slumping (Zhang et al.)





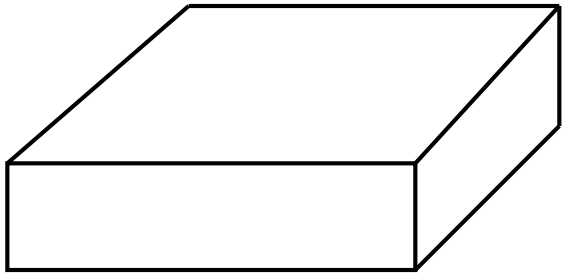
- Simple, Reliable, Mature
- Producing good and consistent results
- Need to reduce mandrel cost & schedule



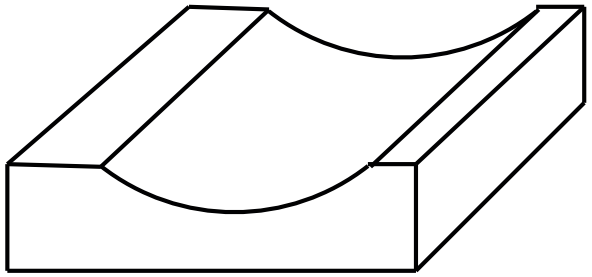
Three Developments Since Chandra

- **Fast and accurate measurement of segmented mirrors**
  - Fizeau interferometers
  - Easily designed and built cylindrical null lens
- **Commercially available deterministic polishing machines**
  - QED: Magneto-Rheological Finishing (MRF)
  - ZEEKO: Intelligent Robotic Polishing (IRP)
  - Others….
- **Abundantly and cheaply available large blocks of mono-crystalline silicon**
  - “Perfect” single crystals: “Free” of internal stress
  - High thermal conductivity and relatively low CTE
  - Can be machined using precision wire-EDM

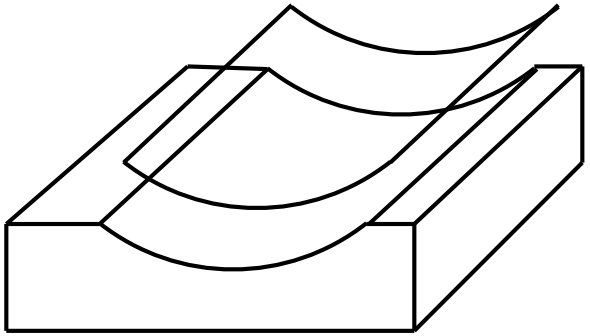
New Method for Fabricating Mirror Segment (Zhang et al.)



1. Procure mono-crystalline silicon: **easy and cheaply** available.
2. Apply heat and chemical treatments to remove all surface/subsurface damage (**fast & cheap**)

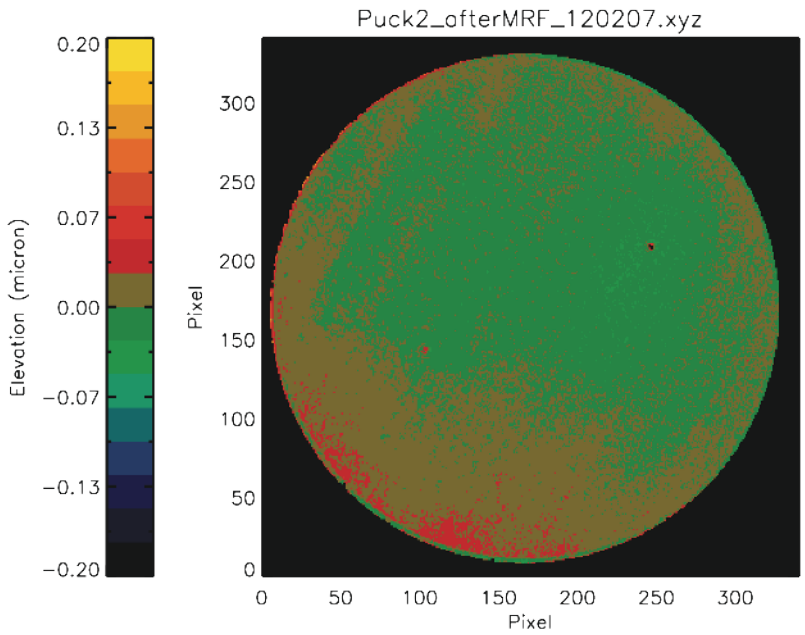


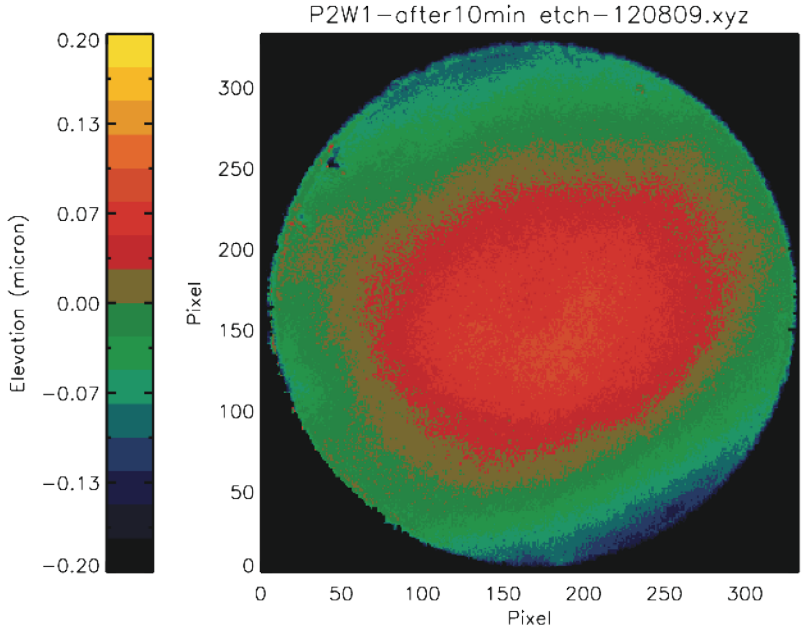
1. W-EDM machine conical shape (**fast & cheap**)
2. Apply heat and chemical treatments to remove damage (**fast & cheap**).
3. Polish using modern deterministic technique to achieve excellent figure and micro-roughness (**fast & cheap? Need demonstration**)



1. Slice off (using W-EDM) the thin mirror segment (**fast & cheap**)
2. Apply heat and chemical treatment to remove all damage from back and edges (**fast & cheap**)

Proof of Principle:
Fabricate and then Light-weight





Before Light-weighting
55 mm thick (~0.1”)

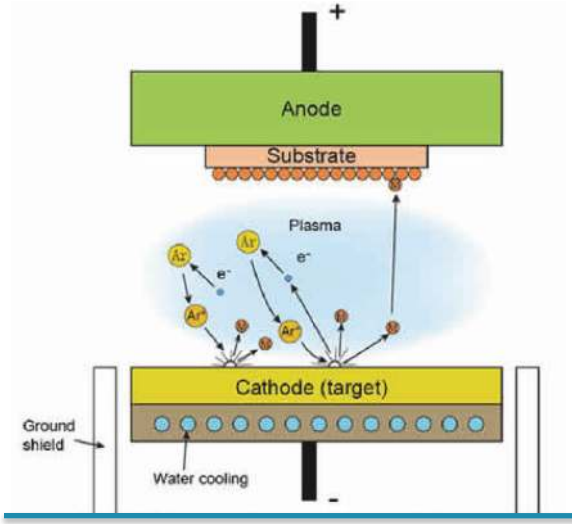
After Light-weighting:
~2 mm thick (~0.5”)

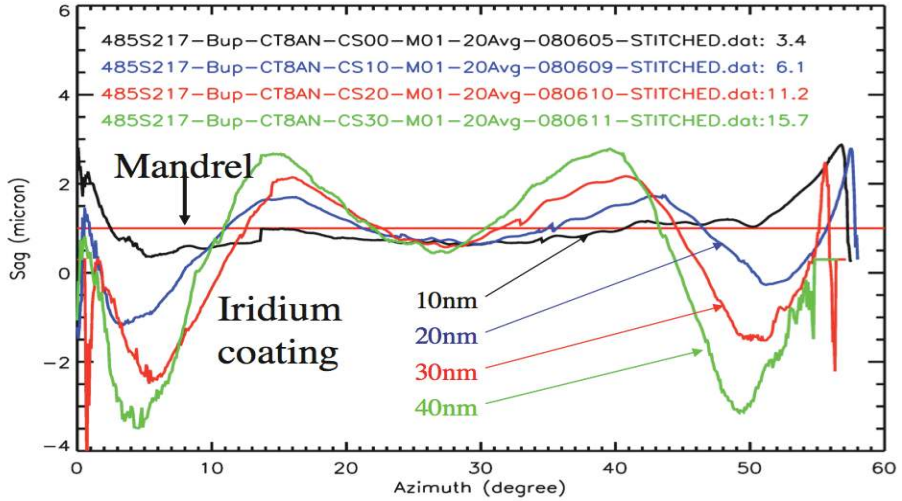
1. **What’s causing the degradation from ~0.1 to ~0.5”?**
2. **Would light-weighting to 0.5mm work as well?**

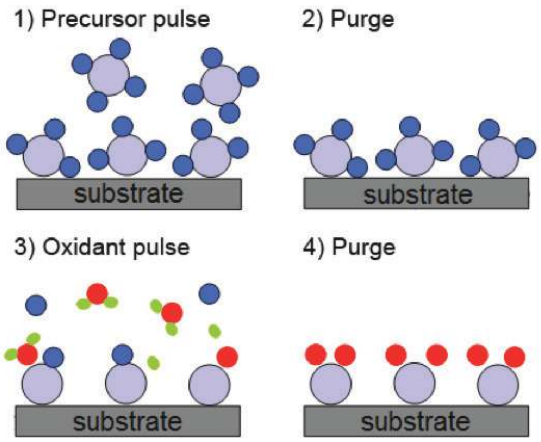
Progression of Work

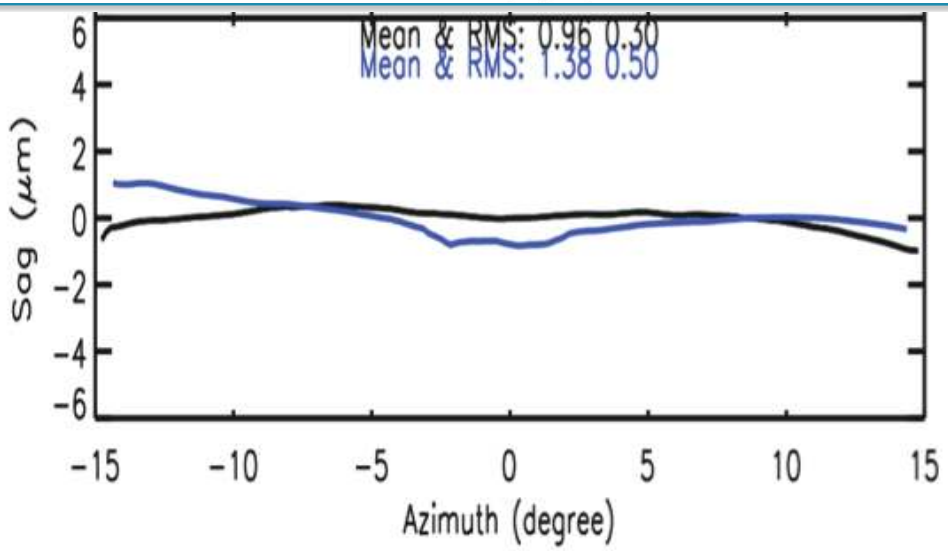
- **FY2102:** Demonstrate principle using flat mirrors – 2012 (**almost done**)
  - Polish a thick 55mm flat mirror
  - Slice off a wafer ~1mm thick
- **FY2013:** Make separate parabolic/hyperbolic segments or combined P-H segment (**lining up companies**)
- **FY2014:** Minimize cost maximize production efficiency

Coating: Sputter vs. ALD (Chan et al.)

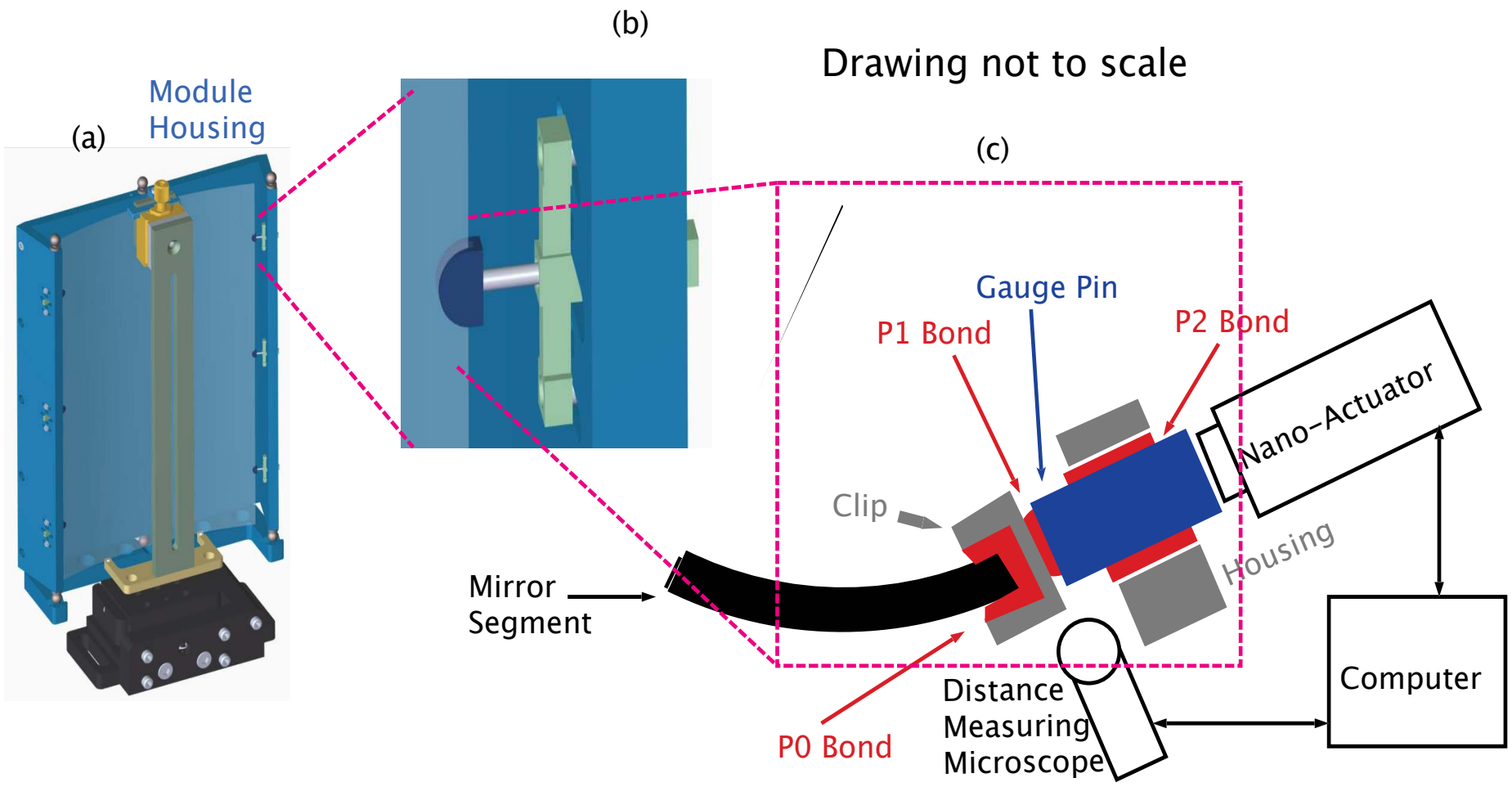






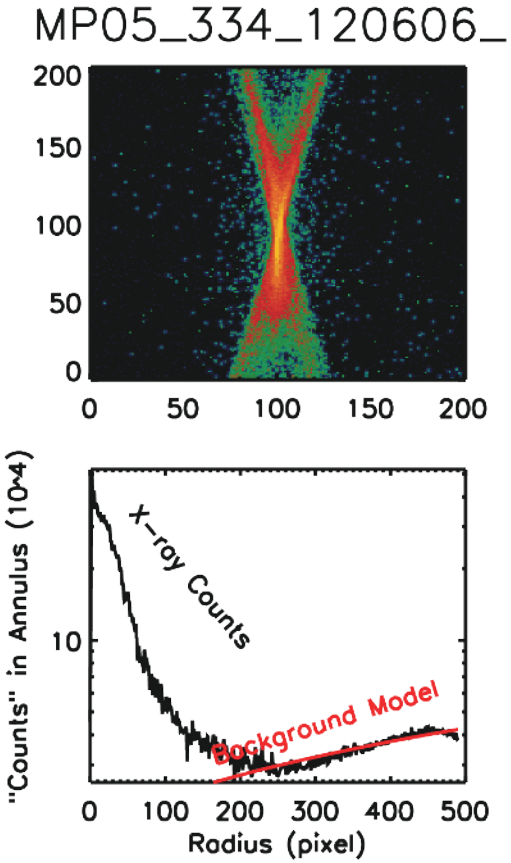


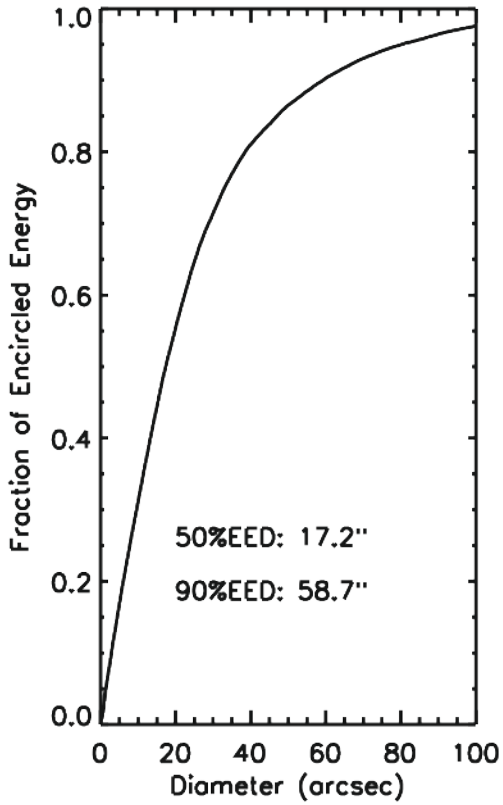
Alignment and Bonding (Biskach et al.)



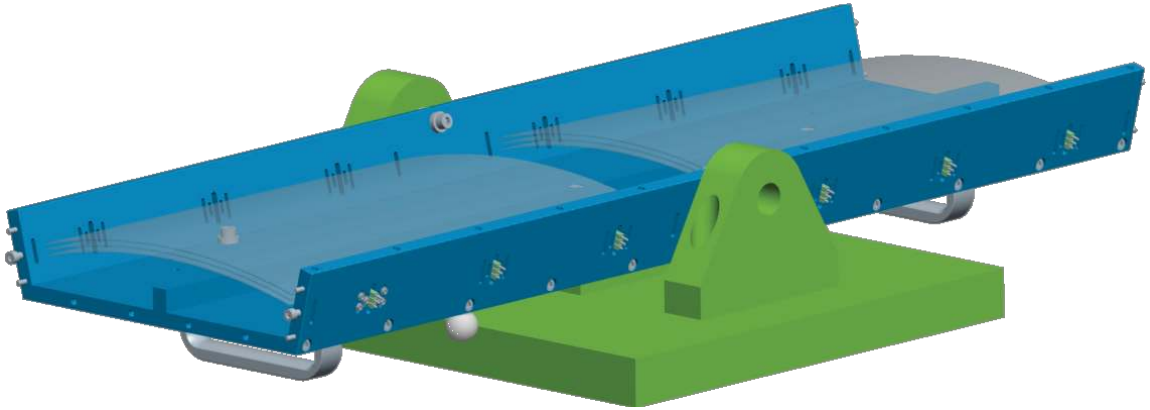
Technology Development Module (X-ray Performance Test)

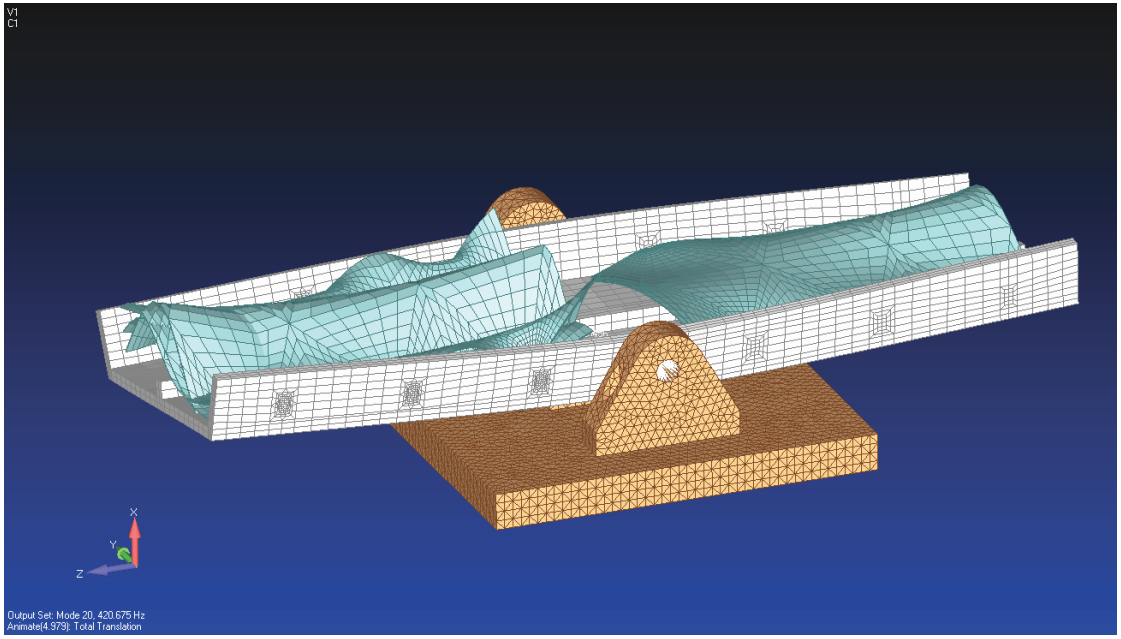
3 Pairs
Co-aligned
Bonded





Module Engineering and Environmental Testing (McClelland et al.)





- Vibration test fixture designed and built
- Static and dynamic analyses completed
- Test being conducted today

Important Issues Being Worked On

- **Forming mandrels**
  - Increase rate of production
  - Decrease cost of production
- **Coating (Sputtering & Atomic layer deposition)**
  - Minimize figure distortion due to stress
- **Thermal environments**
  - CTE mismatch between mirror and housing
  - Potential lack of thermal equilibrium between mirror and housing
- **Epoxy instability**
  - Cure over long periods of time
  - Sensitivity to moisture
  - Visco-elasticity

Prospects

- **Near term (1 to 2 yrs)**
  - XMM's angular resolution: ~10 arcseconds
  - Suzaku's weight and cost
  - To enable AXSIO, N-CAL, N-XGS, N-WFI, and Explorer missions
- **Long term (3 to 10 yrs)**
  - Chandra's angular resolution or better
  - Suzaku's weight and cost per
  - To enable Generation-X, SMART-X…

Necessary and Sufficient Conditions for Making Good X-ray Optics

- Reasonable and adequate funding
- Competent people
- Good ideas
- Clear and well-formulated objectives

Acknowledgements

PCOS Program Office

ROSES/SAT

ROSES/APRA

GSFC/IRAD