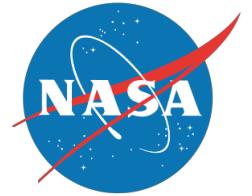


Next Generation X-ray Optics: High Resolution, Light Weight, and Low Cost

William W. Zhang

NASA Goddard Space Flight Center



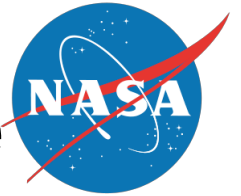
NGXO Team

M.P. Biskach¹, P.N. Blake, K.W. Chan², M. Hong¹,
L.D. Kolos, J.R. Mazzarella¹, R.S. McClelland¹, T.T. Saha,
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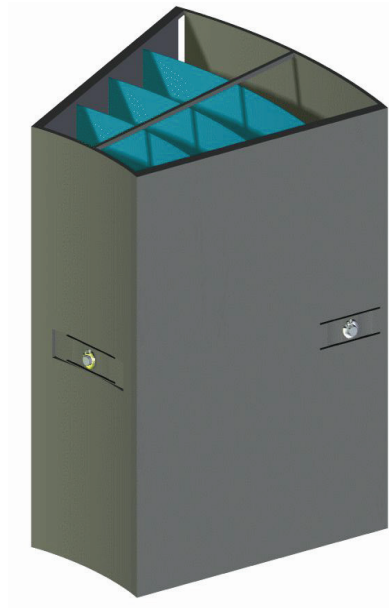
J.A. Carter, J.A. Gaskin, W.D. Jones,
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NASA Marshall Space Flight Center



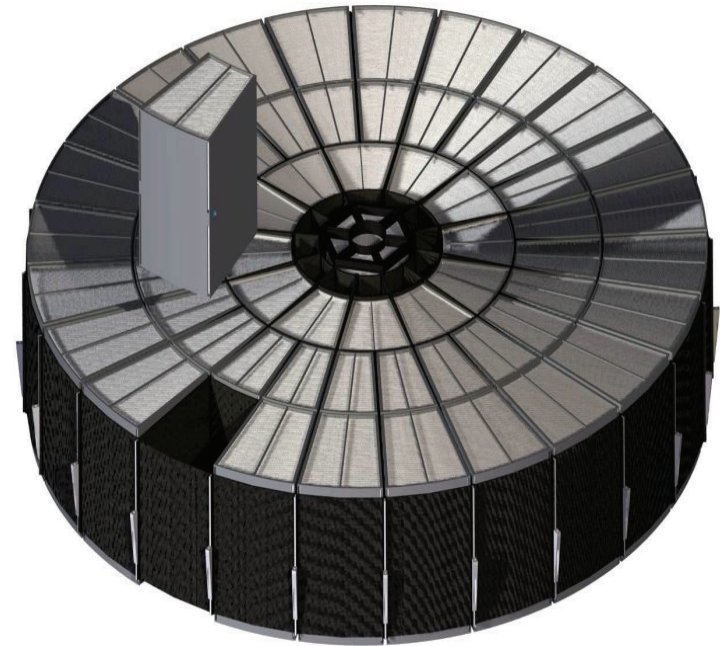
Process of Building a Telescope



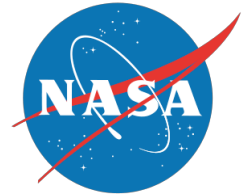
$\sim 10^4$ Mirror
Segments



$\sim 10^2$ Modules
Each containing
 $\sim 10^2$ mirror segments



One or several
mirror assemblies

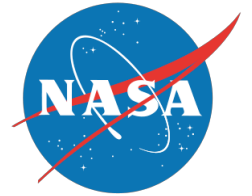


Three Metrics

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



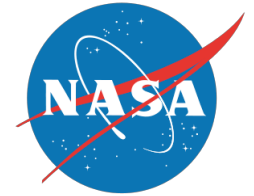
Objectives



- **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



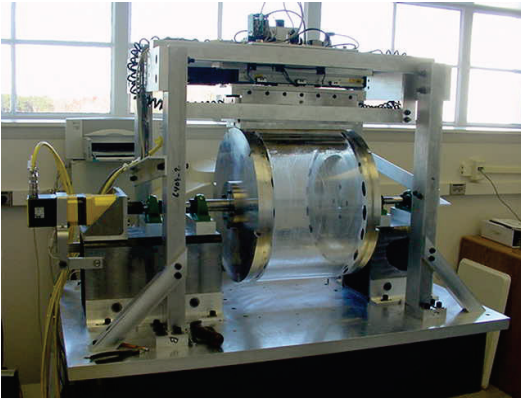
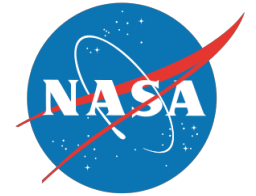
Development History & Future



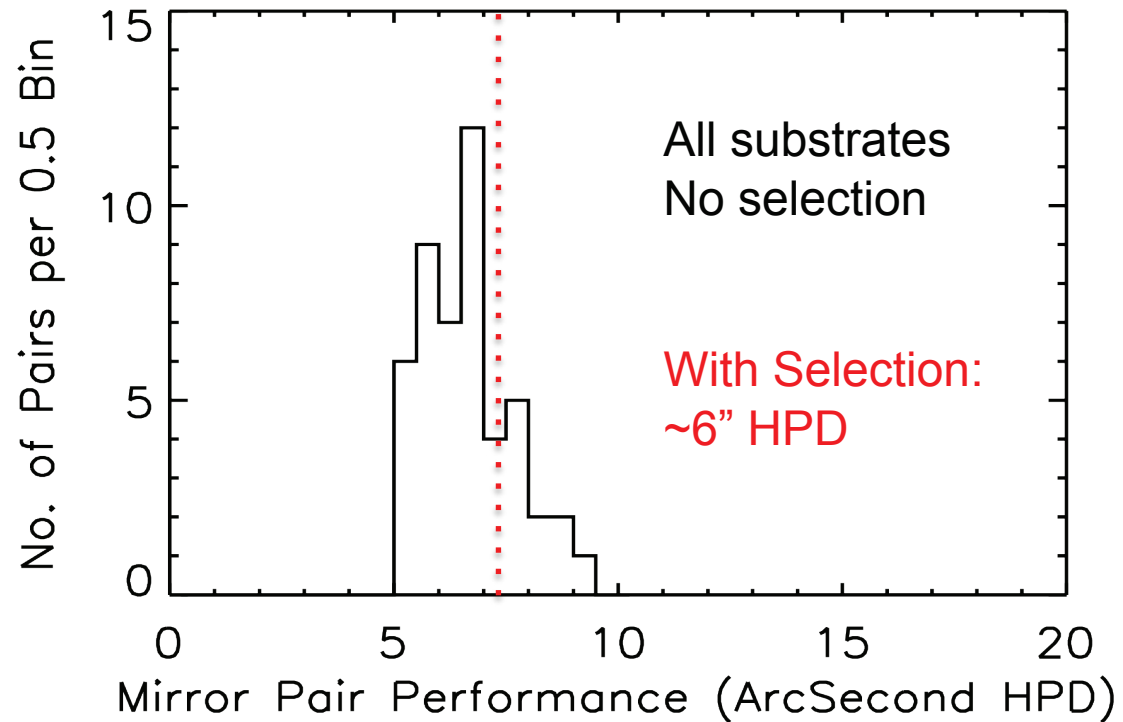
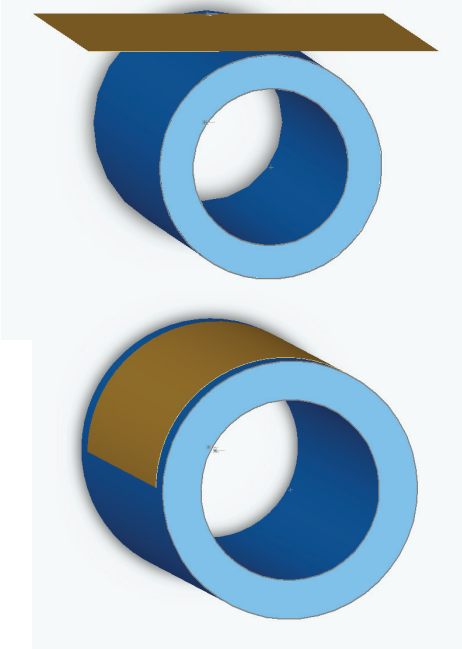
Year	Mirror Segment		Alignment & Bonding		
	Technique	Contribution to HPD (")	Technique	Contribution to Single Pair HPD (")	Contribution to Multiple Pair HPD (")
2002	Slumped glass with epoxy replication	60	Optical Alignment Pathfinder	?	?
2007	Slumped glass	10	Mattress	12	?
2010		8	Smart Bonding	10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



Glass Slumping (Zhang et al.)

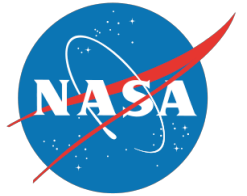


- Simple, Reliable, Mature
- Producing good and consistent results
- Need to reduce mandrel cost & schedule





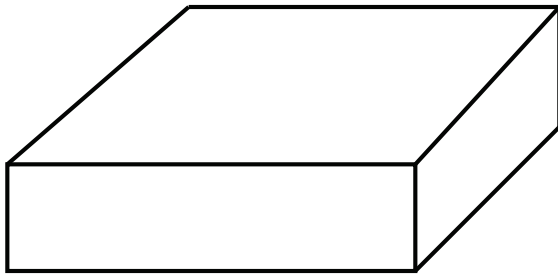
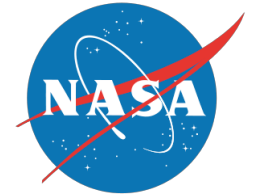
Three Developments Since Chandra



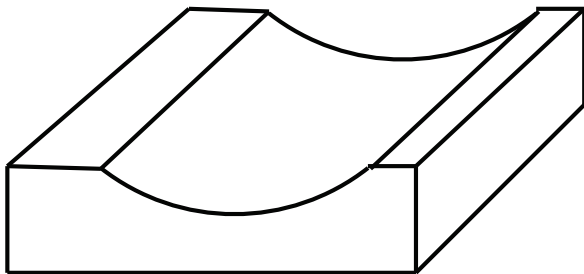
- **Fast and accurate measurement of segmented mirrors**
 - Fizeau interferometers
 - Easily designed and built cylindrical null lens
- **Commercially available deterministic polishing machines**
 - QED: Magneto-Rheological Finishing (MRF)
 - ZEEKO: Intelligent Robotic Polishing (IRP)
 - Others....
- **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



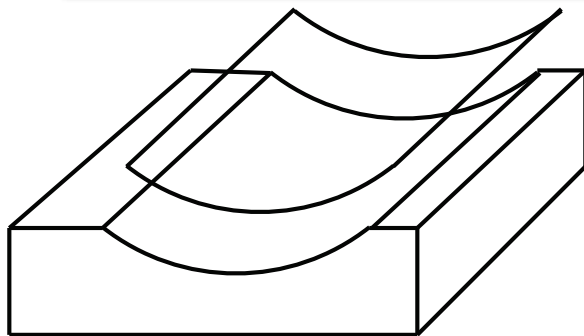
New Method for Fabricating Mirror Segment (Zhang et al.)



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



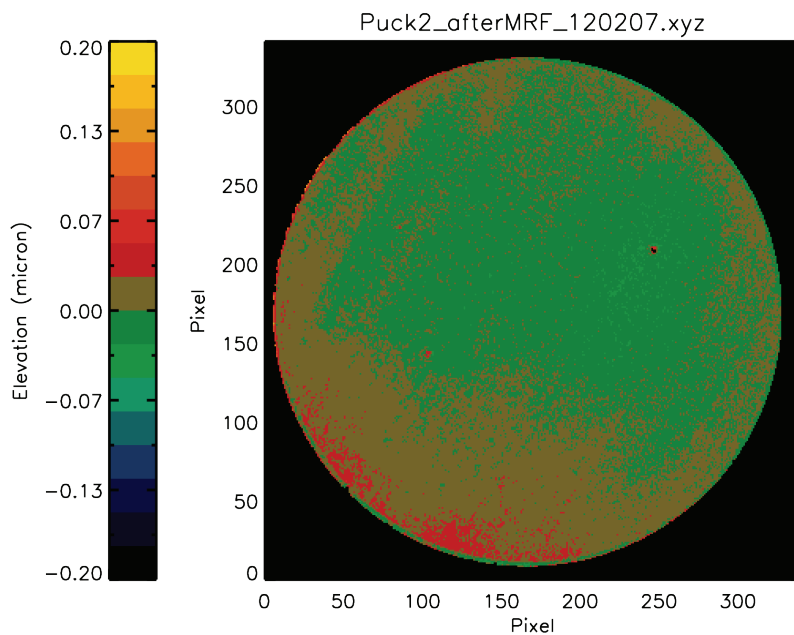
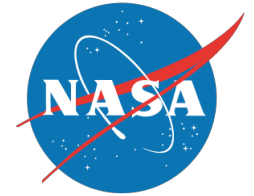
1. W-EDM machine conical shape (**fast & cheap**)
2. Apply heat and chemical treatments to remove damage (**fast & cheap**).
3. Polish using modern deterministic technique to achieve excellent figure and micro-roughness (**fast & cheap? Need demonstration**)



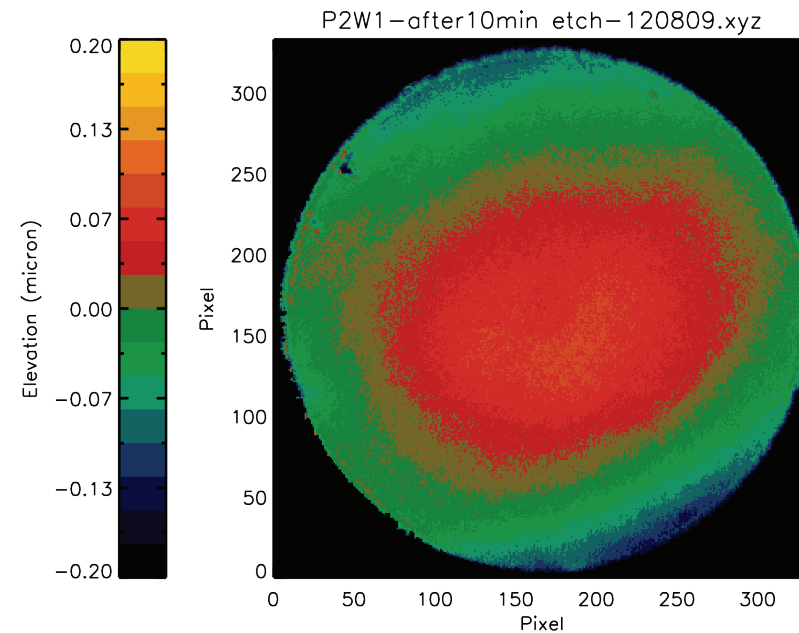
1. Slice off (using W-EDM) the thin mirror segment (**fast & cheap**)
2. Apply heat and chemical treatment to remove all damage from back and edges (**fast & cheap**)



Proof of Principle: *Fabricate and then Light-weight*



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

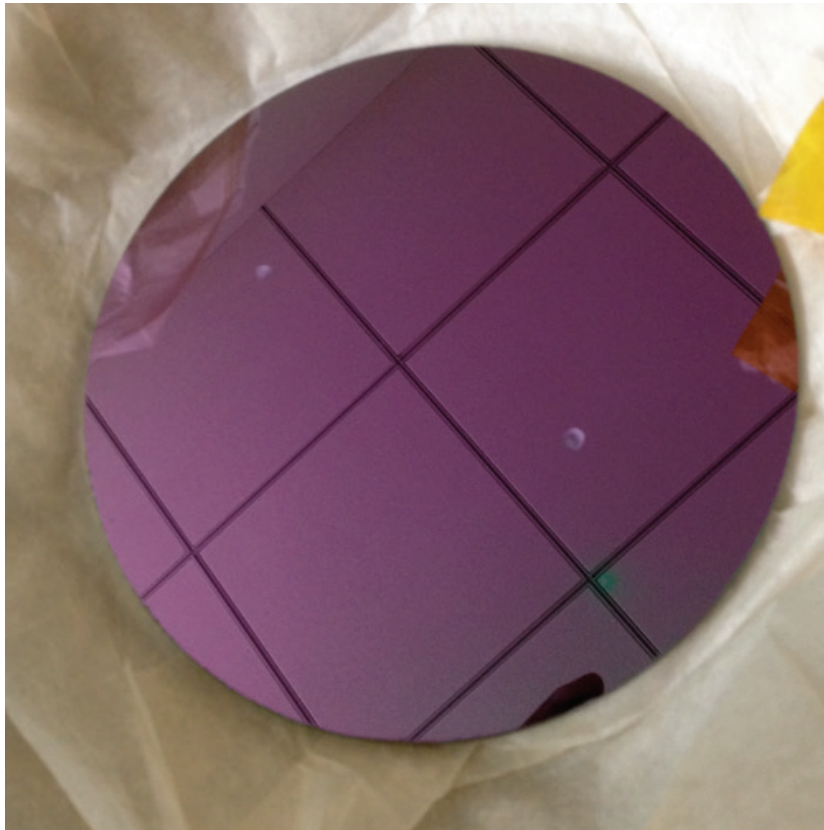
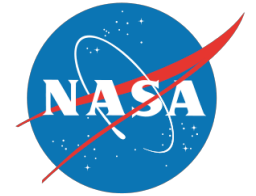


After Light-weighting:
~2 mm thick (~0.5")

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



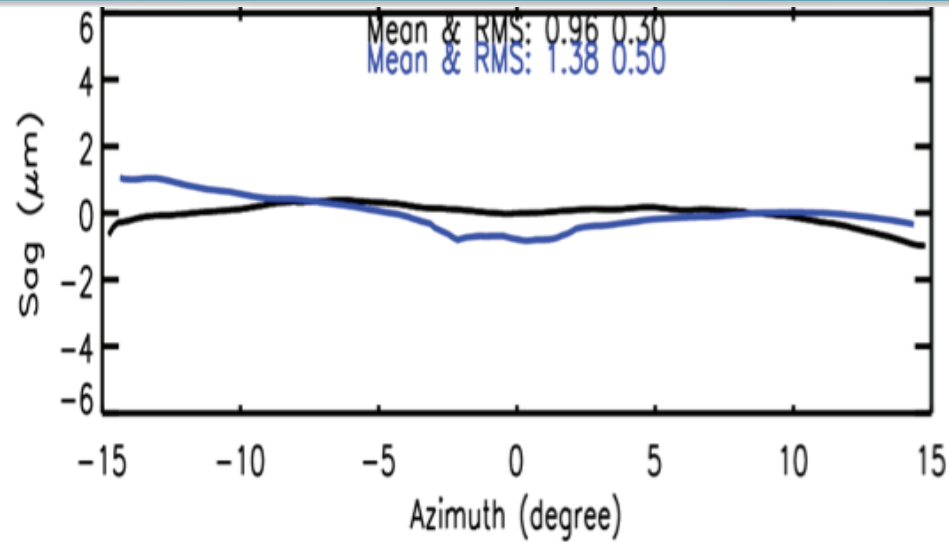
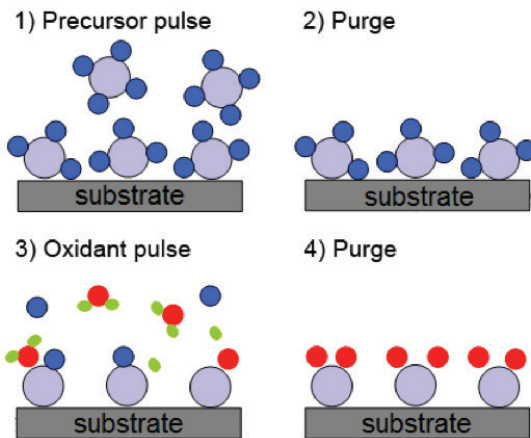
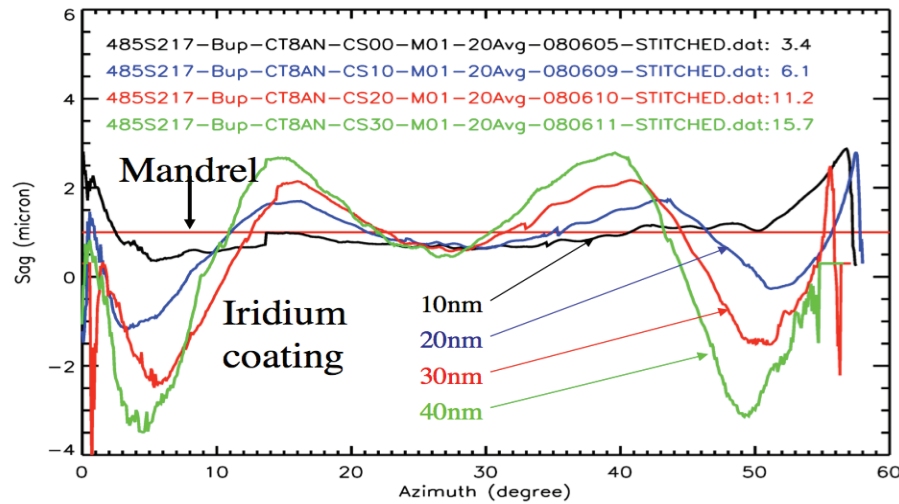
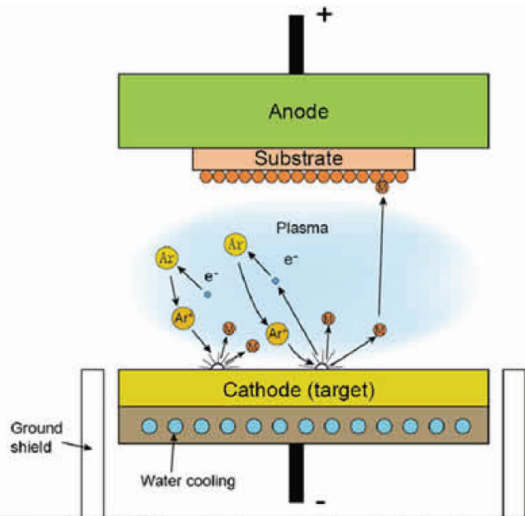
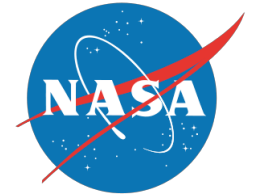
Progression of Work



- **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

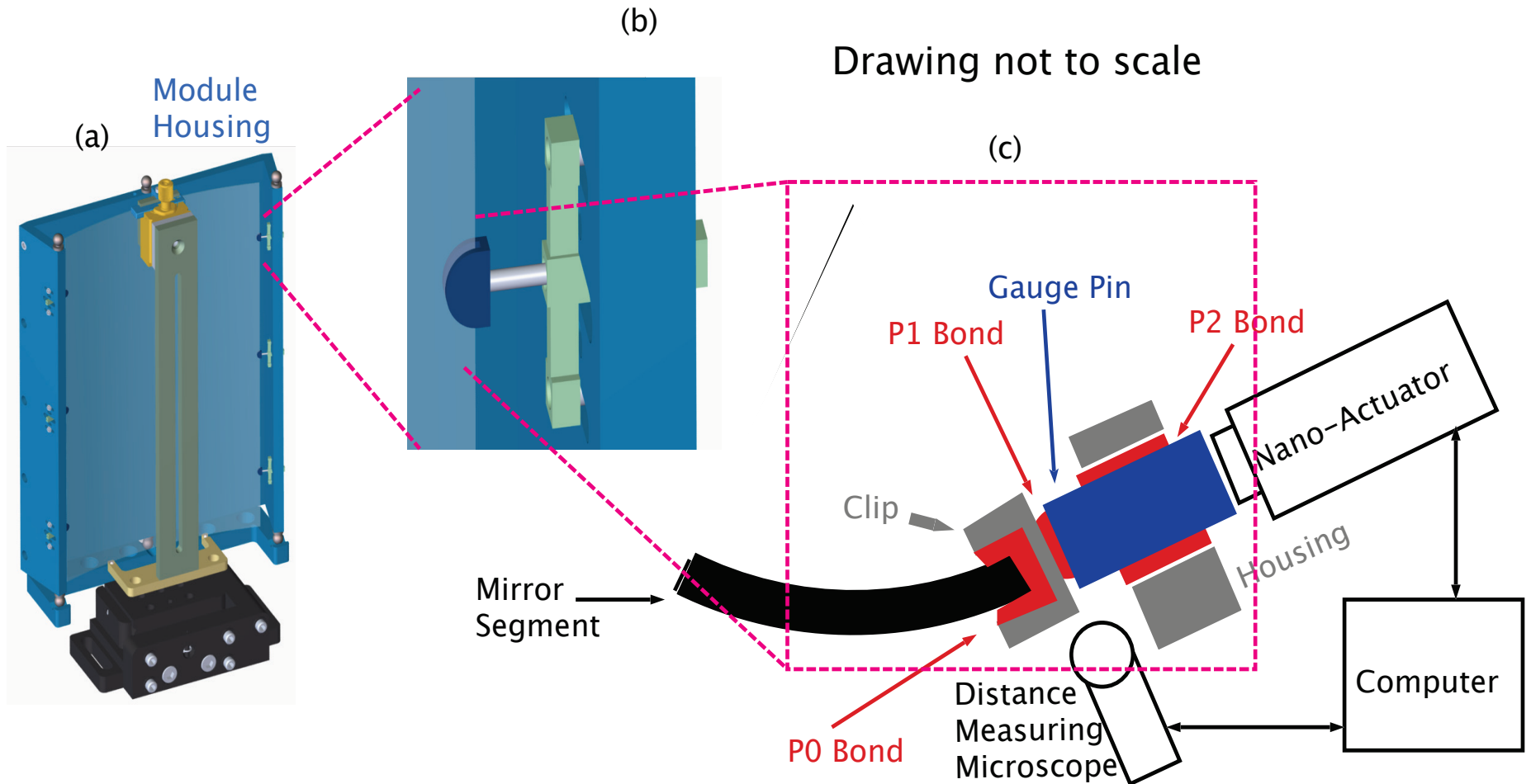
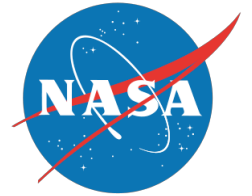


Coating: Sputter vs. ALD (Chan et al.)



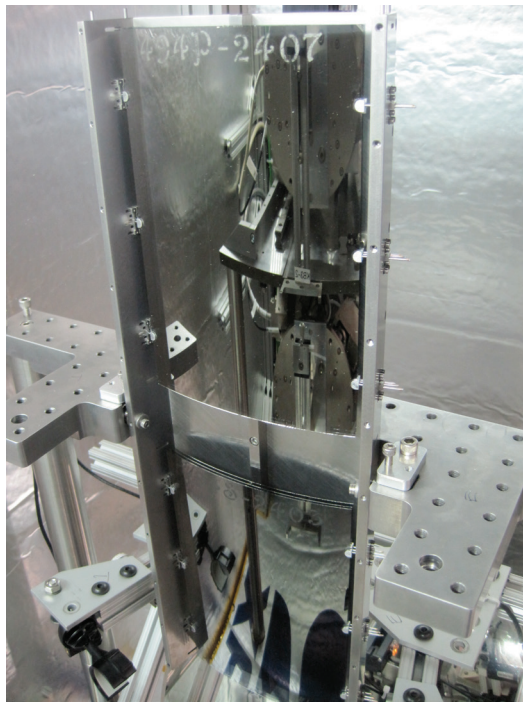
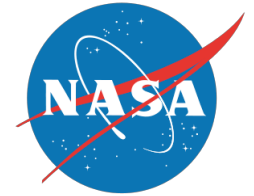


Alignment and Bonding (Biskach et al.)



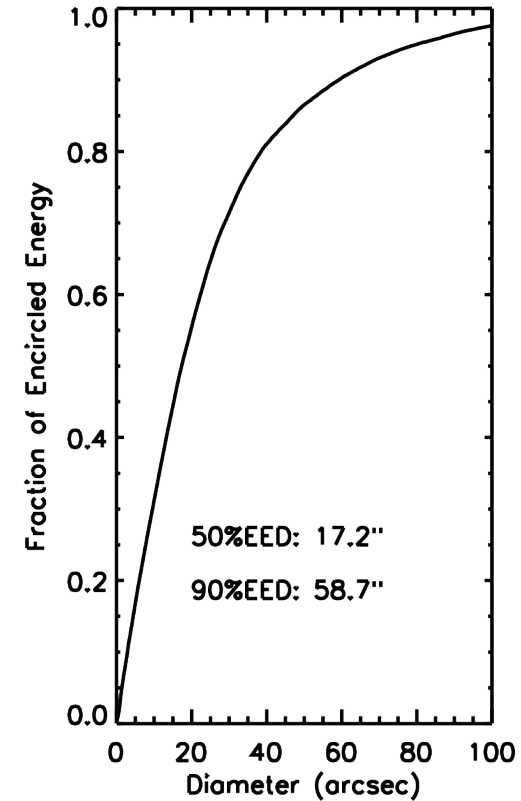
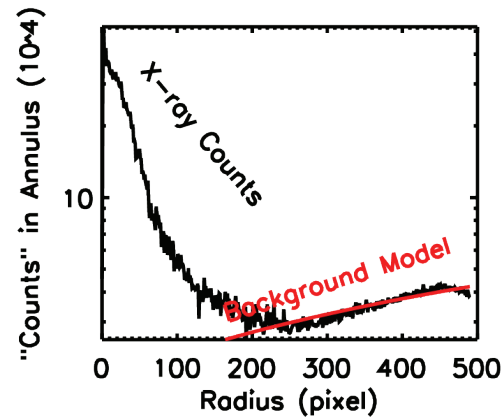
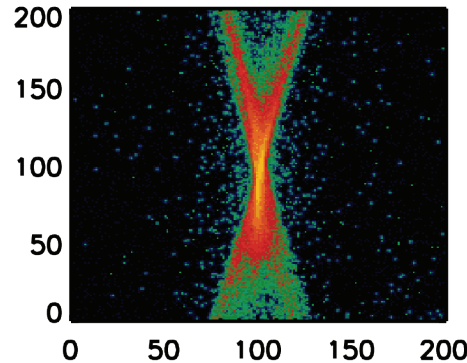


Technology Development Module (X-ray Performance Test)



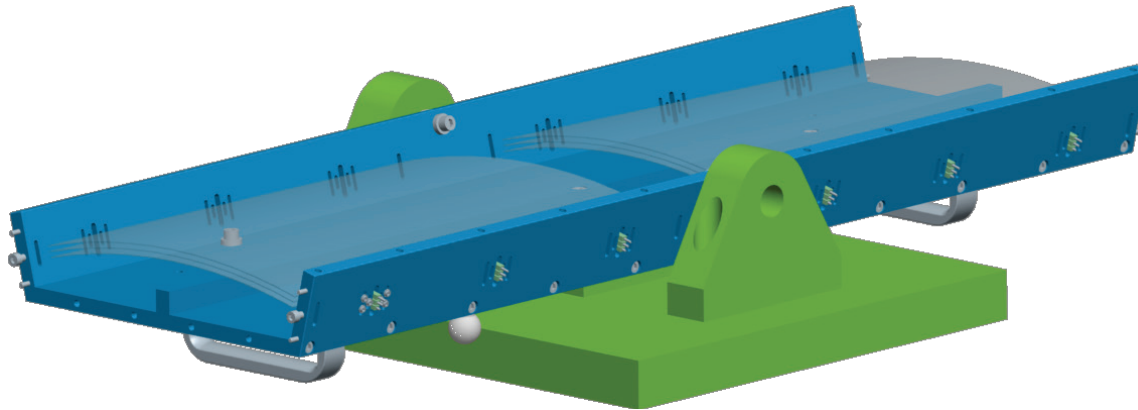
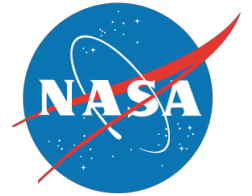
**3 Pairs
Co-aligned
Bonded**

MP05_334_120606_1144_3Pair_100sec_Full.TIF

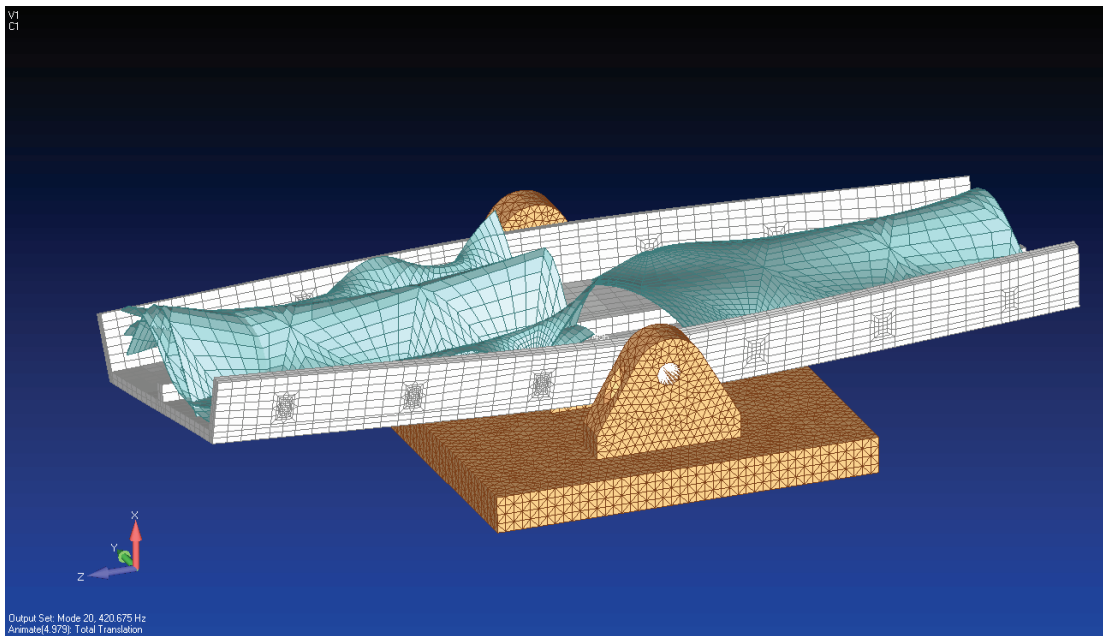




Module Engineering and Environmental Testing (McClelland et al.)

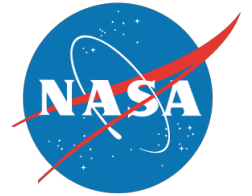


- Vibration test fixture designed and built
- Static and dynamic analyses completed
- Test being conducted today





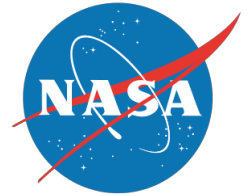
Important Issues Being Worked On



- **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



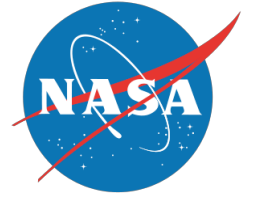
Prospects



- **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...



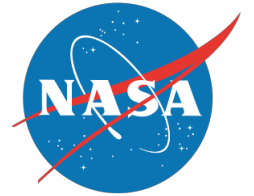
Necessary and Sufficient Conditions for Making Good X-ray Optics



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



Acknowledgements



PCOS Program Office

ROSES/SAT

ROSES/APRA

GSFC/IRAD