Lightweight X-ray Optics

William W. Zhang

NASA Goddard Space Flight Center

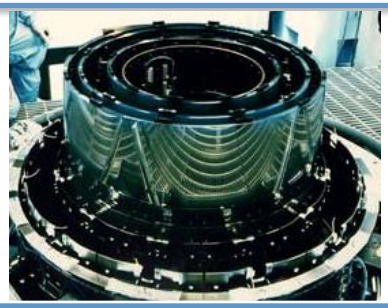
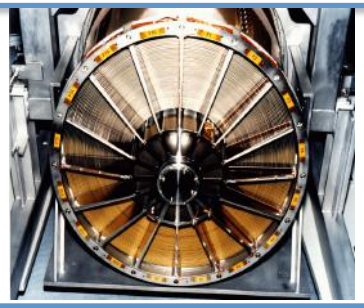
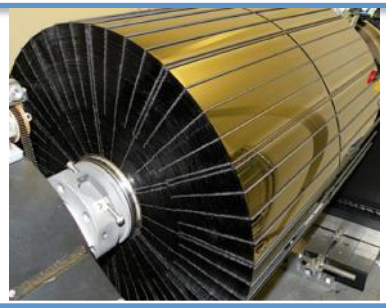
Metrics of X-ray Optics

- PSF: Angular Resolution
- Mass per unit Effective Area
- Cost per unit Effective Area

Definition of Progress:

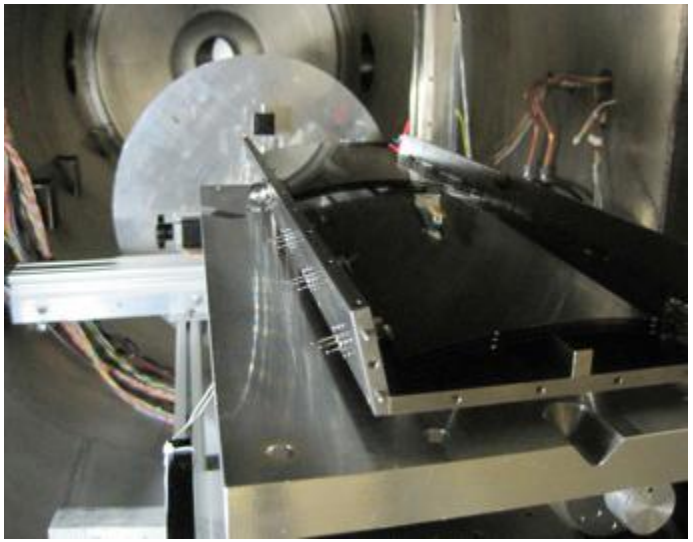
10 times better than existing technology in one or more of the three metrics

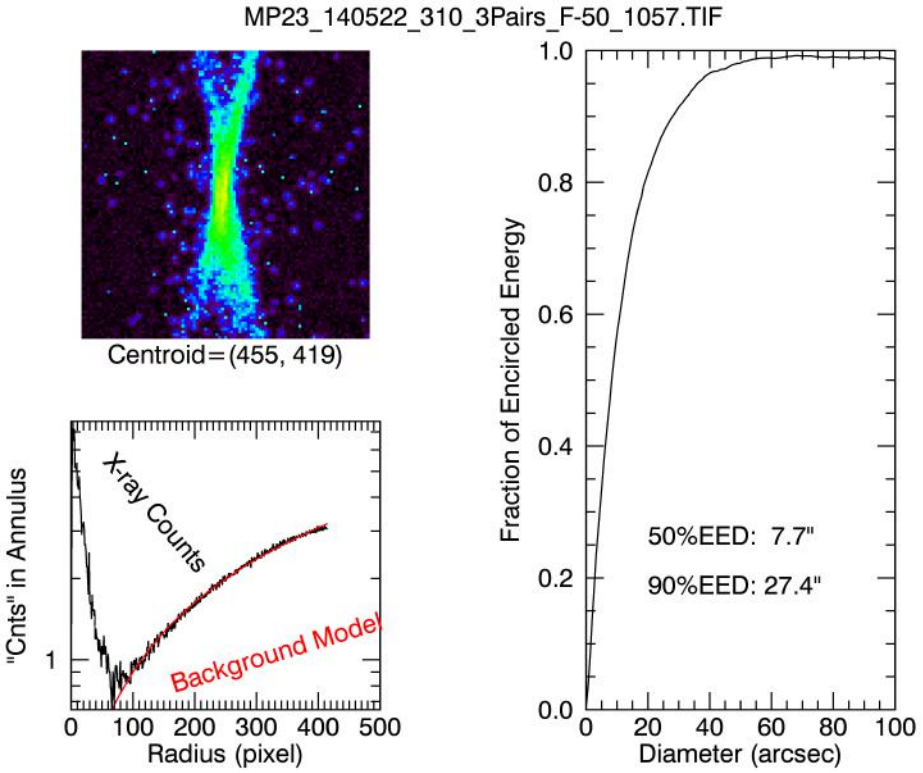
Missions in Operations

	Chandra	XMM-Newton	NuSTAR
Agency	NASA	ESA	NASA
PSF (“ HPD)	0.5	15	58
Mass/EffArea (kg/m^2)	~18,000	~2,000	~180
Cost/EffArea ($/m², 2013$)	~$10,000M	~$413M	~$50M

Technology for IXO





Based on glass slumping. Mature.
Ready for missions requiring 10” PSF.

Future Missions

	PSF (“ HPD)	Mirror Area (m^2)
HST	0.1	5
Chandra	0.5	19
TMT	~0.1	~700
Athena	5	~700
X-ray Surveyor	~0.5	~700
Probes, Explorers	0.1 - 10	20 - 200

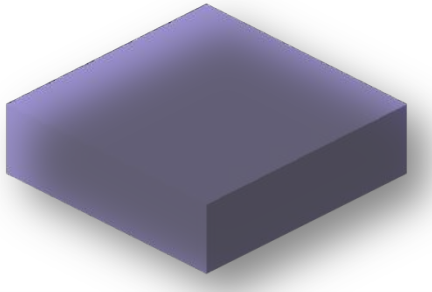
Three Challenges

- **Mirror Fabrication**
  Make ~10^2 m^2 of lightweight optics
  at reasonable cost in reasonable time
- **Coating**
  Coat 15nm of iridium without degrading figure
- **Alignment and Bonding**
  Integrate ~10^4 mirrors into an assembly
  at reasonable cost in reasonable time

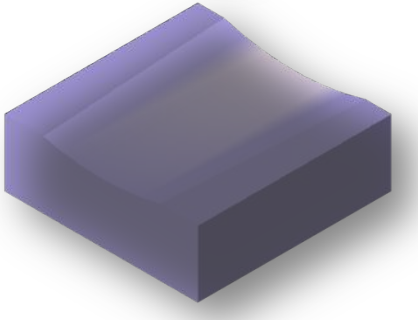
Mirror Fabrication

- **Use single crystal silicon**
  - Perfect structure, no internal stress
  - Low density, high thermal conductivity, low CTE, and high stiffness
- **Use "grind & polish"**
  - Proven technique for making high quality optics
- **Develop and perfect**
  - A process to make thin & lightweight mirrors
  - A mass-production process to lower cost and production time

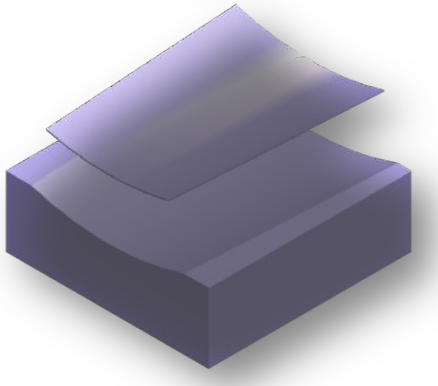
Mirror Fabrication Concept



Single crystalline silicon:
Stress free

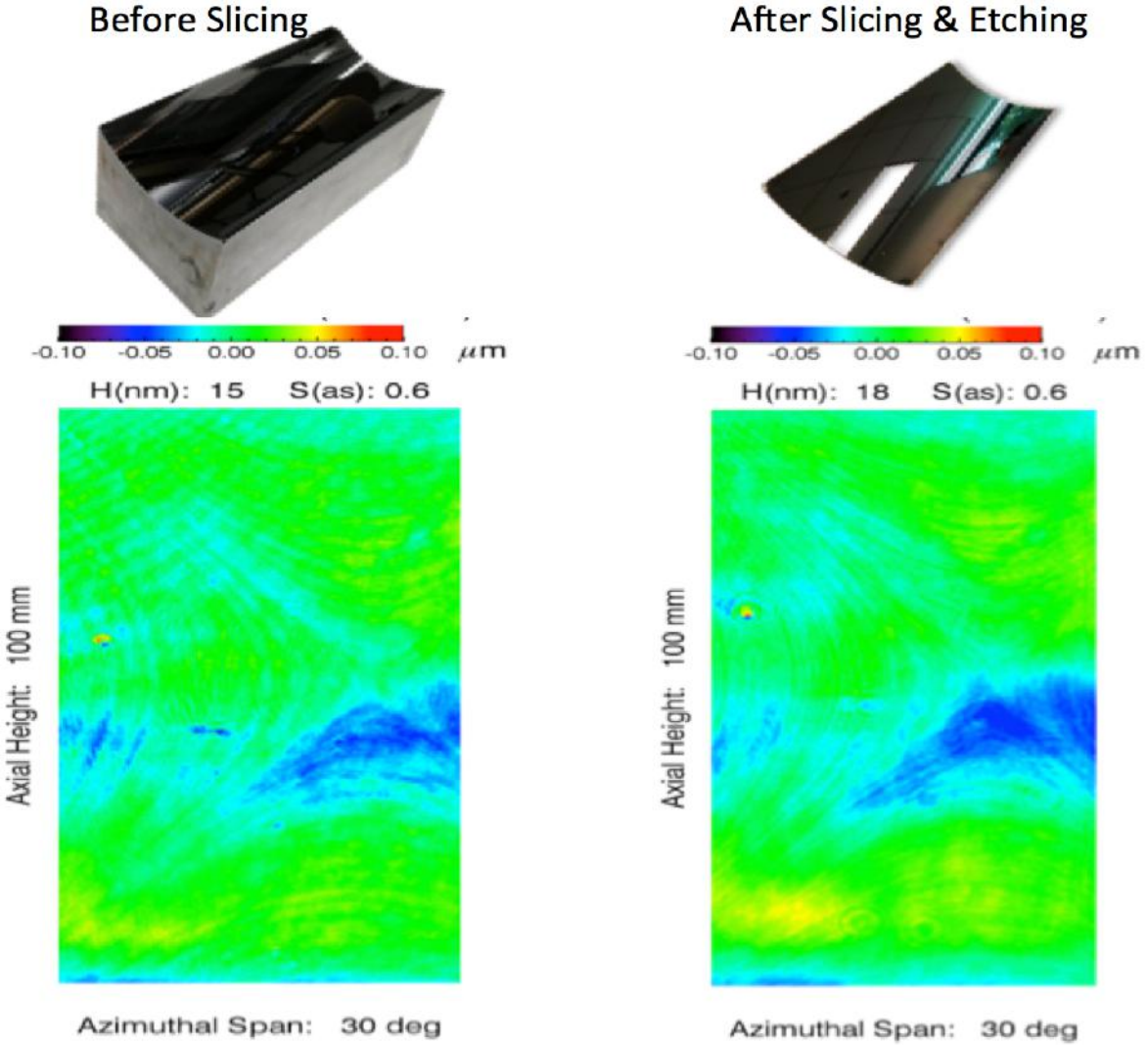


A high quality mirror, made with existing polishing



Light-weighting:
Slicing and removal of damage by acid etch

Concept Proven



Coating Concept

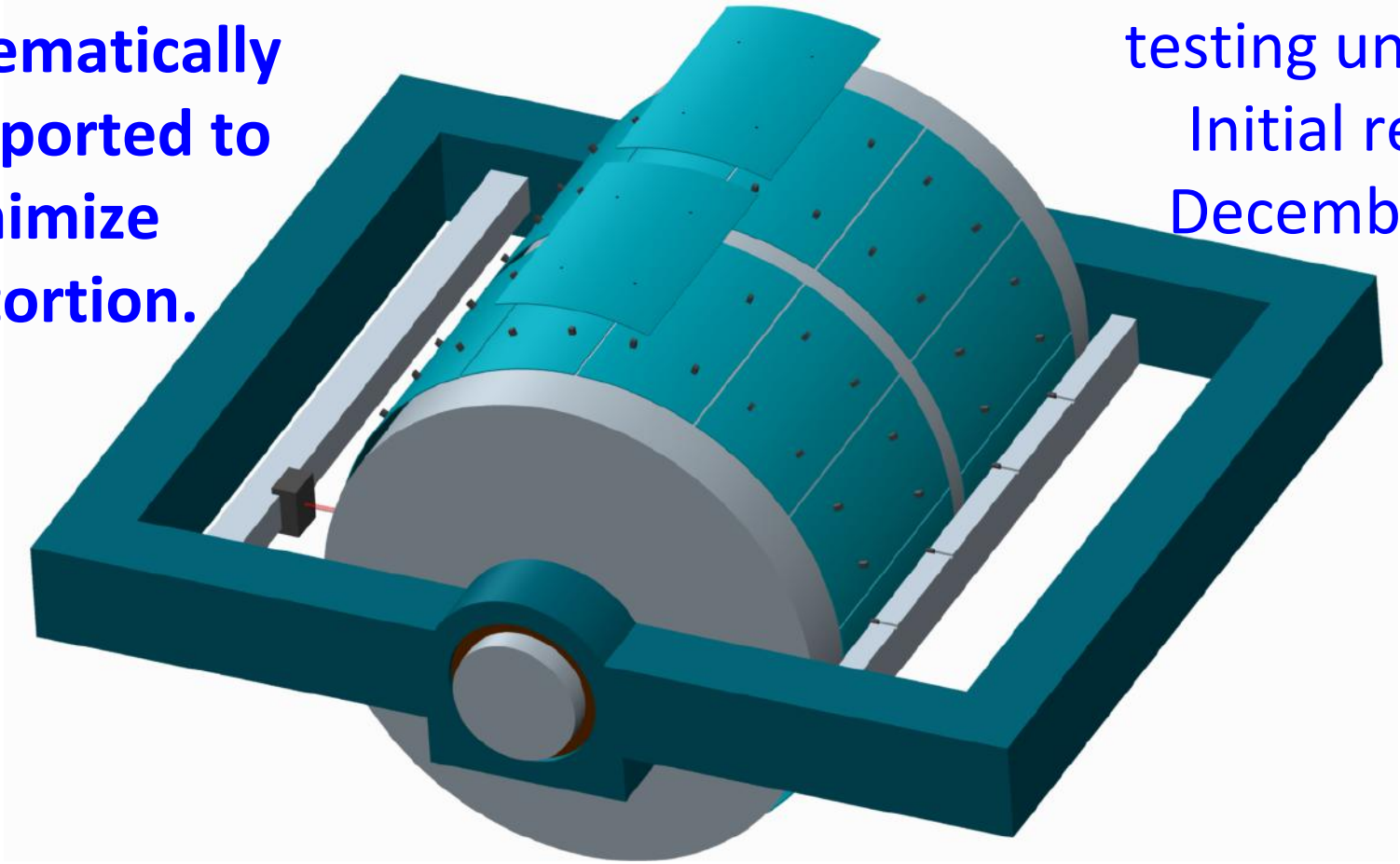
- Sputter both sides of silicon mirrors with 15nm of iridium to minimize net stress
- Anneal coated mirrors to eliminate residual net stress

Coating Concept Proven

	Bare Wafers	Iridium Coated on Both Sides	After Annealing
Wafer#1	SiWafer-SPSJ01-Front-M01-150713_1305	SiWafer-SPSJ01-Front-M05-150901_1057	SiWafer-SPSJ01-Front-M06-151019_1305
Wafer#2	SiWafer-SPSJ02-Front-M01-150713_1308	SiWafer-SPSJ02-Front-M05-150901_1020	SiWafer-SPSJ02-Front-M06-151019_1259

Alignment and Bonding Concept

Each mirror kinematically supported to minimize distortion.



Implementation and testing underway. Initial results by December 2016.

Status and Prospects

- **Slumped glass technology ready for making 10” X-ray telescopes**
  - 10 times lighter than XMM-Newton’s, comparable angular resolution
  - 10 times better angular resolution than Suzaku’s, comp arable weight
- **Single crystal silicon mirror technology under development**
  - Mirrors currently at ~2” level
  - Diffraction-limited performance possible (~0.1”)
  - Coating, alignment and bonding being worked on
  - ~2” X-ray images expected for December 2016
  - Likely to reach 1” by 2020, ready to support the X-ray Surveyor mission

Other Development Efforts

- **Efforts to improve the glass slumping process**
  - MPE, Germany (Winter et al.)
  - OAB, Italy (Gigho et al.)
- **Efforts to improve slumped glass mirrors**
  - Differential deposition at MSFC (Ramsey et al.) & RXO (Windt)
  - Piezo adjustable at SAO & PSU (Reid et al.)
  - Magnetic smart material at Northwestern Univ. (Ulmer et al.)
  - Ion implant at MIT (Schattenburg et al.)
- **Efforts to grind and polish thin full shells**
  - OAB, Italy (Pareschi et al.)
  - MSFC (Gubarev et al.)
- **Efforts to improve mirror bonding**
  - Using solder at MIT (Schattenburg et al.)

Next Generation X-ray Optics Team

K. D. Allgood[1], M.P. Biskach[1], K.W. Chan[2], J.R. Mazzarella[1], R.S. McClelland[1], J. Niemeyer[1], A. Numata[1], L.G. Olsen, R.E. Riveros[2], T.T. Saha, M.J. Schofield[1], M.V. Sharpe[1], P.M. Solly[1], W.W. Zhang

NASA Goddard Space Flight Center

[1] Stinger Ghaffarian Technologies, Inc.

[2] University of Maryland, Baltimore County

J.M. Carter, J.A. Gaskin, W.D. Jones, J.J. Kolodziejczak, S.L. O'Dell

NASA Marshall Space Flight Center

Undergraduate Interns

Dillon Martin

University of Central Florida

Tony Zheng

Stony Brook University

Acknowledgement

This work has been funded by

NASA through

APRA and SAT Programs.