SAO

Technology Development Status: Adjustable Grazing Incidence X-ray Optics for Sub-arcsecond Imaging

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Science Motivation – ASTRO2010

"Science frontier area: The epoch of reionization"

- Emergence of first galaxies
  - Hot halos around massive galaxies with large SFR
- Early stages of supermassive black hole merger tree
  - $10^3\ M_\odot$
- Detailed chemical and dynamical study of hot accretion and outflows

"What are the connections between Dark and Luminous matter?"

"How do black holes grow, radiate, and influence their surroundings?"

- Detect and resolve quasar host halos and galaxy groups at $z = 6$
- Feedback and physics in clusters, galaxies, SNR

SMART-X: A mission concept for the 2020's

- NRC NASA Technology Roadmap and X-ray Community Science Team both identify sub-arcsec imaging with very large collecting area as critical for future X-ray astronomy missions.
- Mission performance needed to achieve 2020's science (launch by 2030)
  - 0.5 arcsec HPD @ 1 keV (Chandra-like)
  - 30 times Chandra eff. area @ 1 keV
  - 20+ arcmin FOV
  - Advanced detector suite: Active Pixel Imager, 1 arcsec imaging calorimeter $\Delta E \sim 5$ eV, grating spectrometer $E/\Delta E \sim 4000$
- Minimize development costs for an Observatory mission
  - Chandra-like spacecraft requirements – maximizes heritage, minimizes cost and risk
    - 10 m FL, mass, pointing control and aspect, S/W, Test & Ass'y, thermal
  - Build upon AXSIO architecture/studies/tech development
- To be a competitive mission for the 2020 Decadal
  - Achieve TRL 6 by 2018-2019 for mirror and detectors
  - Need technology funding now to develop light-weight, high angular resolution mirrors.

http://hea-www.cfa.harvard.edu/SMARTX/presentations/smx-rfi-submitted.pdf

Motivation for adjustable bimorph X-ray mirrors

Existing technologies are limited:

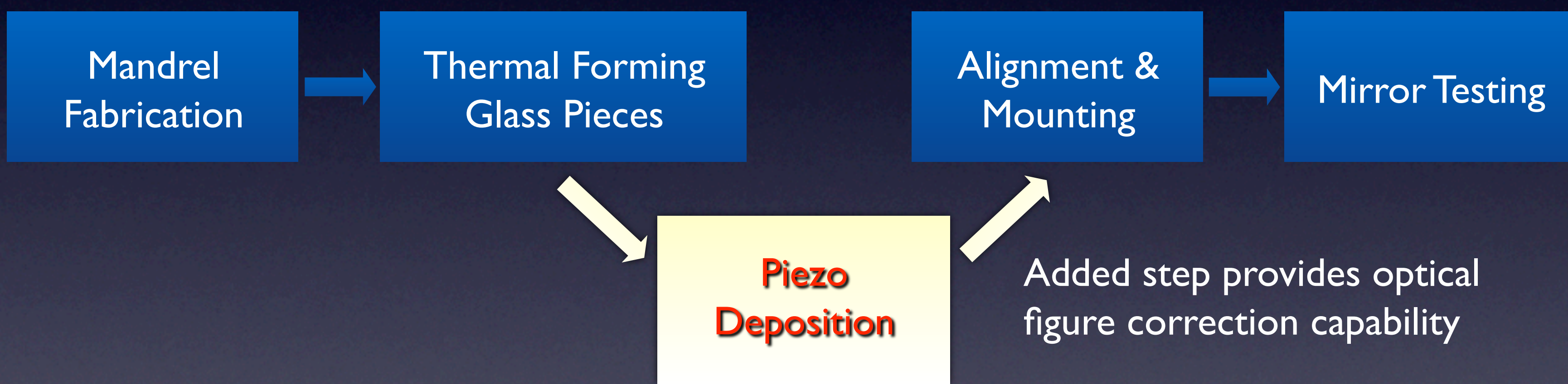
- *Chandra* approach (precisely polished mirrors) too heavy
  - ~ 20,000 kg/m^2 vs. ~ 400 kg/m^2 for SMART-X
- Replication (IXO/AXSIO, XMM...) and pore optics (IXO/Athena) not enough resolution
  - 5 to 10 arcsec HPD vs. 0.5 arcsec HPD

New technical approach — adjustable bimorph mirrors:

- Use replication technologies to enable large collecting area
  - Build upon extensive IXO heritage in mirrors, alignment, mounting
- Bimorph approach: mirror figure adjustable after mounting/alignment
  - Correct fabrication, mounting, gravity release, and thermal errors, either once on the ground, or infrequently (or once) on-orbit

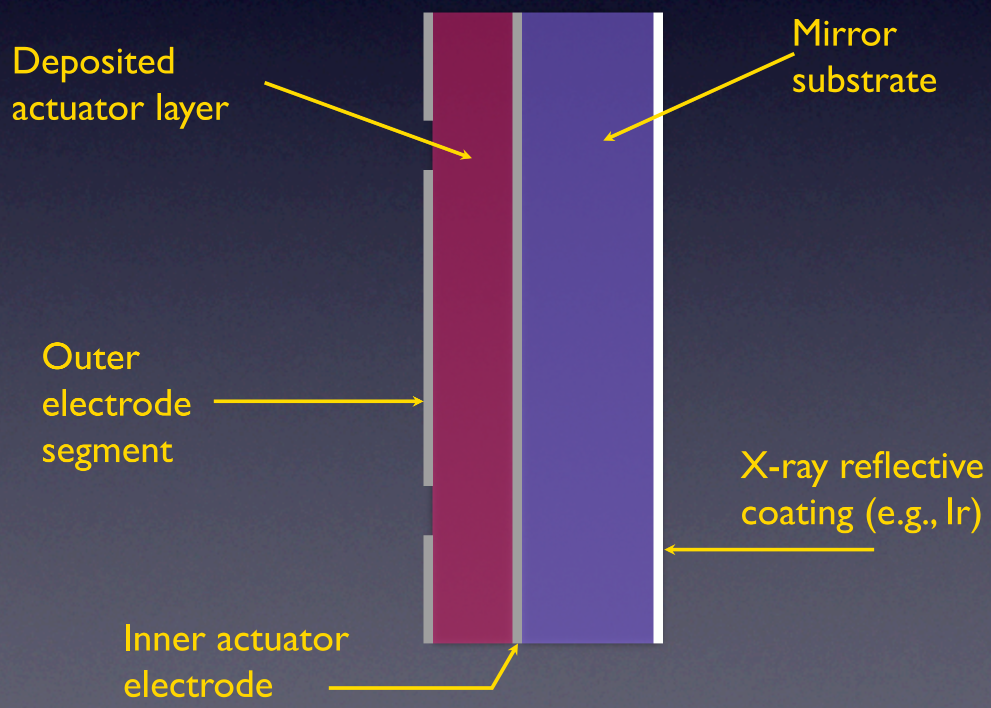
Program builds upon previous NASA investments

IXO/AXSIO production flow in Blue



Adjustable Bimorph Mirror: a path to large area, high-resolution X-ray telescopes

- Thin (~1.5um) piezoelectric film deposited on mirror back surface.
- Electrode pattern deposited on top of piezo layer.
- Energizing piezo cell with a voltage across the thickness produces a strain in piezo parallel to the mirror surface (in two orthogonal directions)



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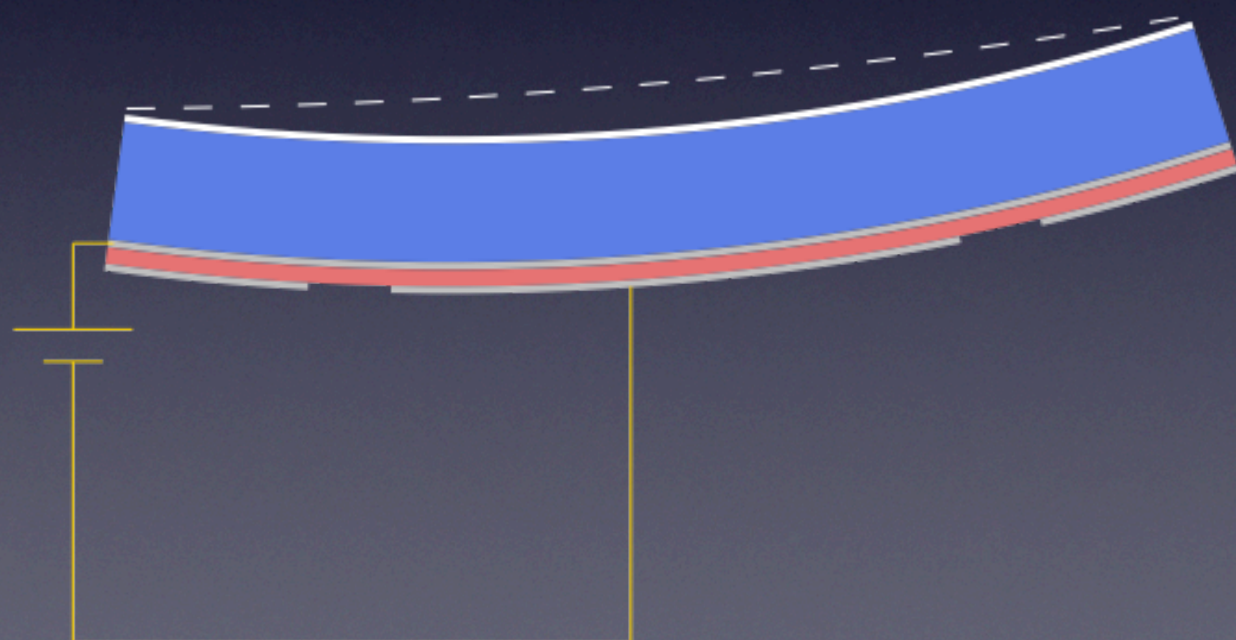

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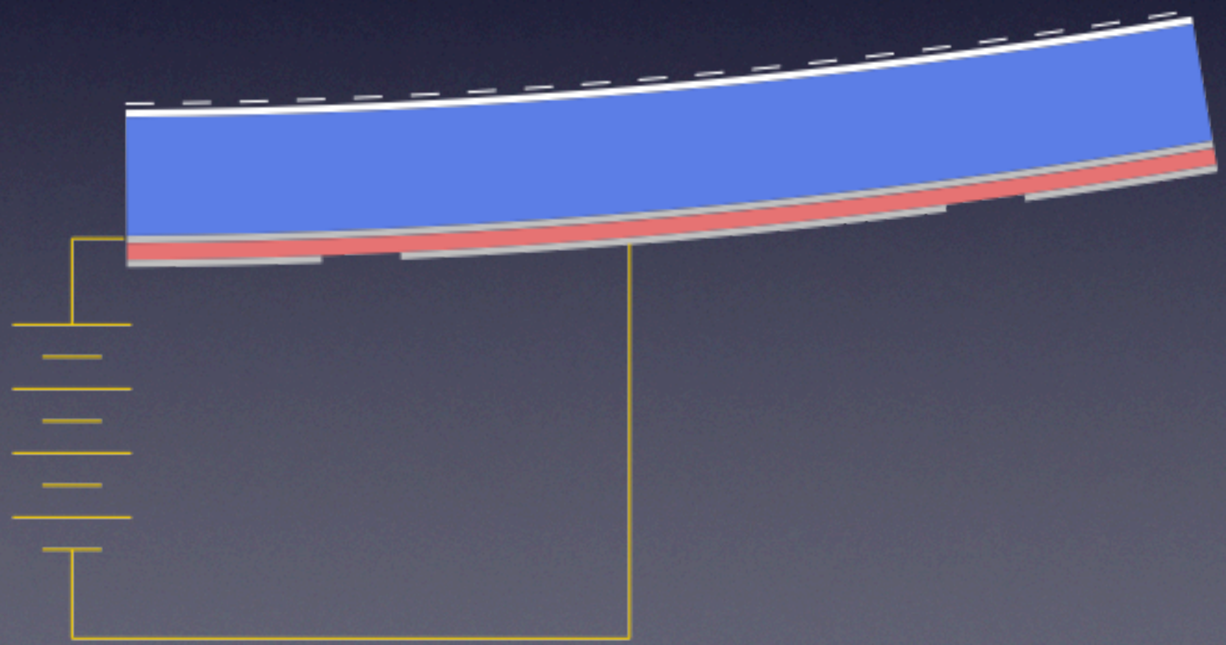
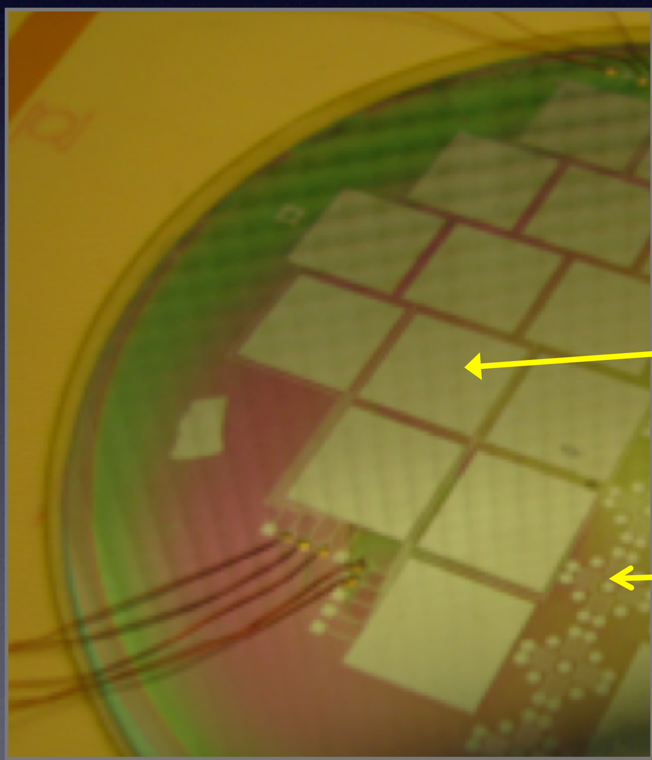
- Electrode pattern deposited on top of piezo layer.
- Energizing piezo cell with a voltage across the thickness produces a strain in piezo parallel to the mirror surface (in two orthogonal directions)Strain produces bending in mirror — ***No reaction structure needed.***
- Optimize the voltages for each piezo cell to minimize the figure error in the mirror.



Adjustable Bimorph Mirror: a path to large-area, high-resolution X-ray telescopes

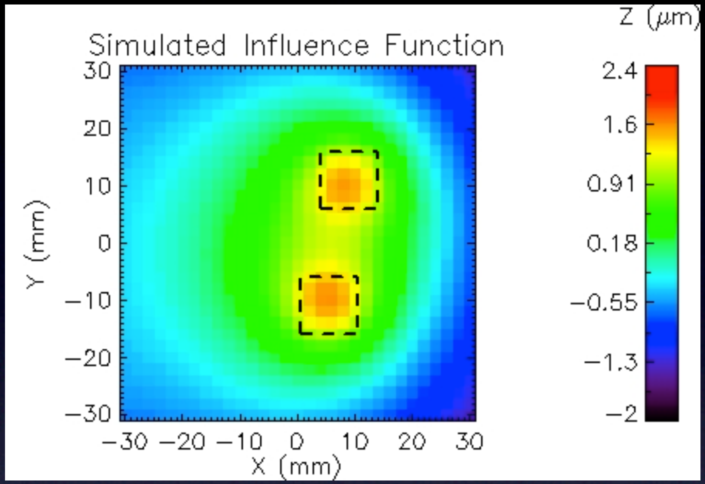
Major accomplishments:

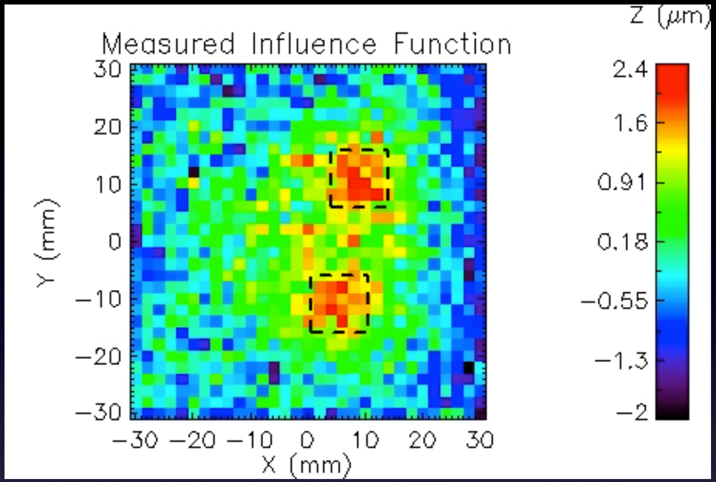
- Deposition of large area piezos on glass (Penn State Materials Lab).
- Modeled and measured influence functions show good agreement.
- Patterning of electrodes on convex side of cylindrical mirror.
- Uniform deposition on convex side of cylindrical mirror.



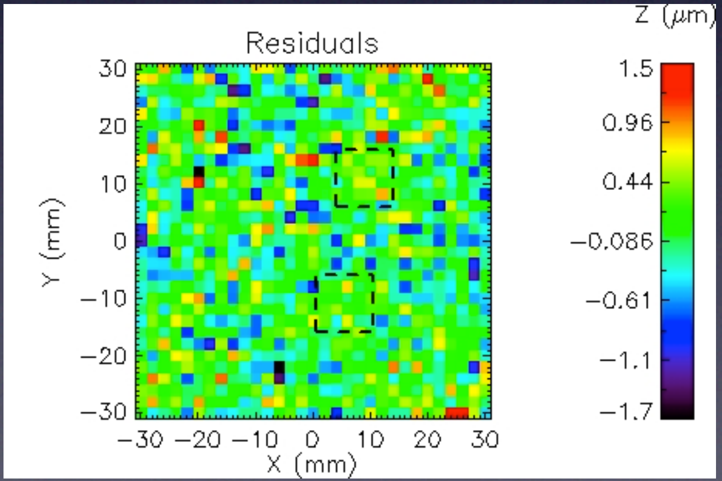
Flat test mirror – 100 mm diameter 0.4 mm Corning Eagle glass with 1.6 μm PZT and 1 cm^2 electrodes.

Measured influence functions match models well

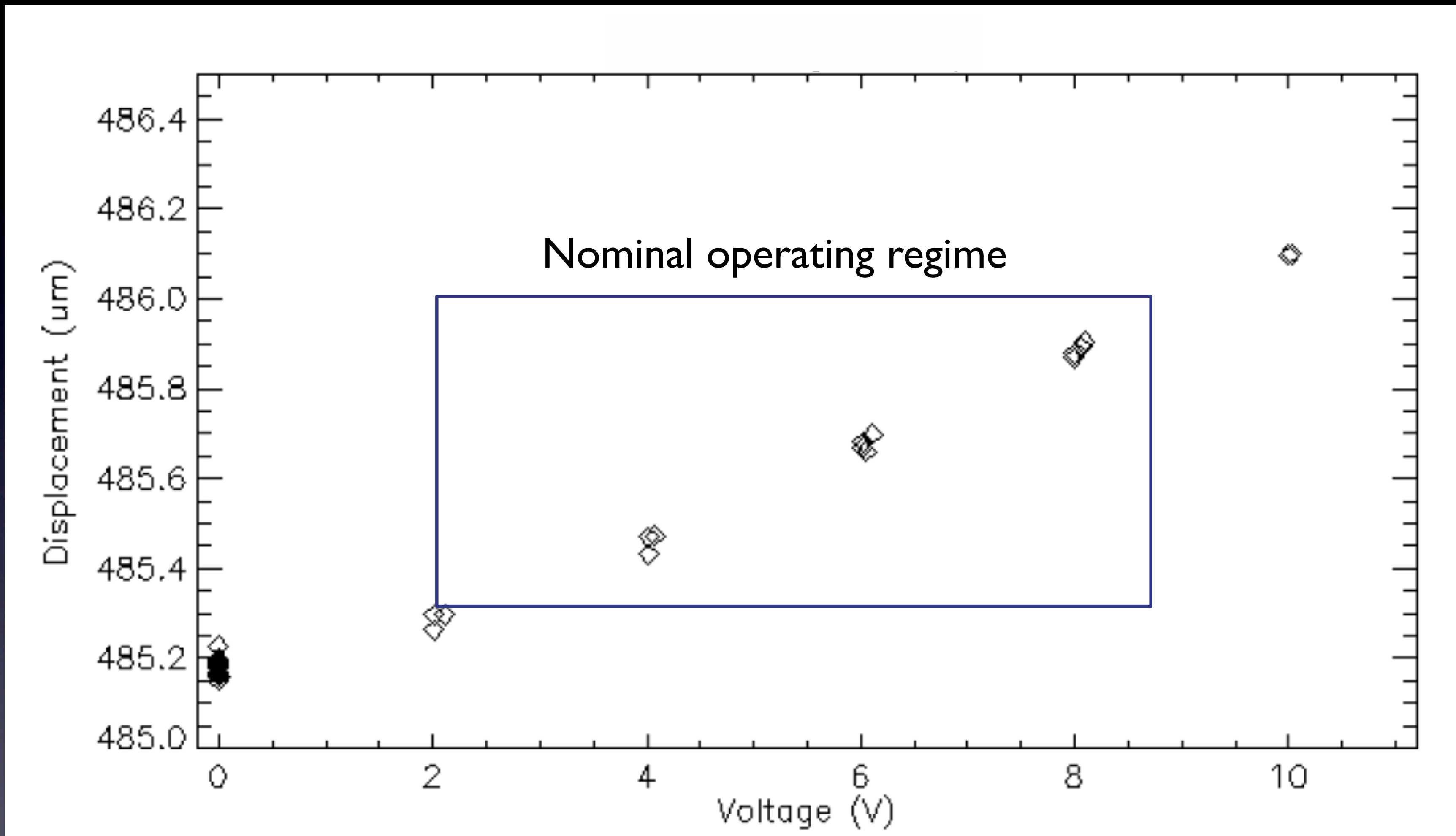




- Test using Corning Eagle™ flat glass, 0.4 mm thick, 100 mm diam., 1 cm^2 piezo cells
- Deflection at 10V is equivalent to 700 ppm strain — meets *SMART-X* 500 ppm requirement.
- Model influence function using FEA
- Residual (measured minus modeled) is the same amplitude as metrology noise.

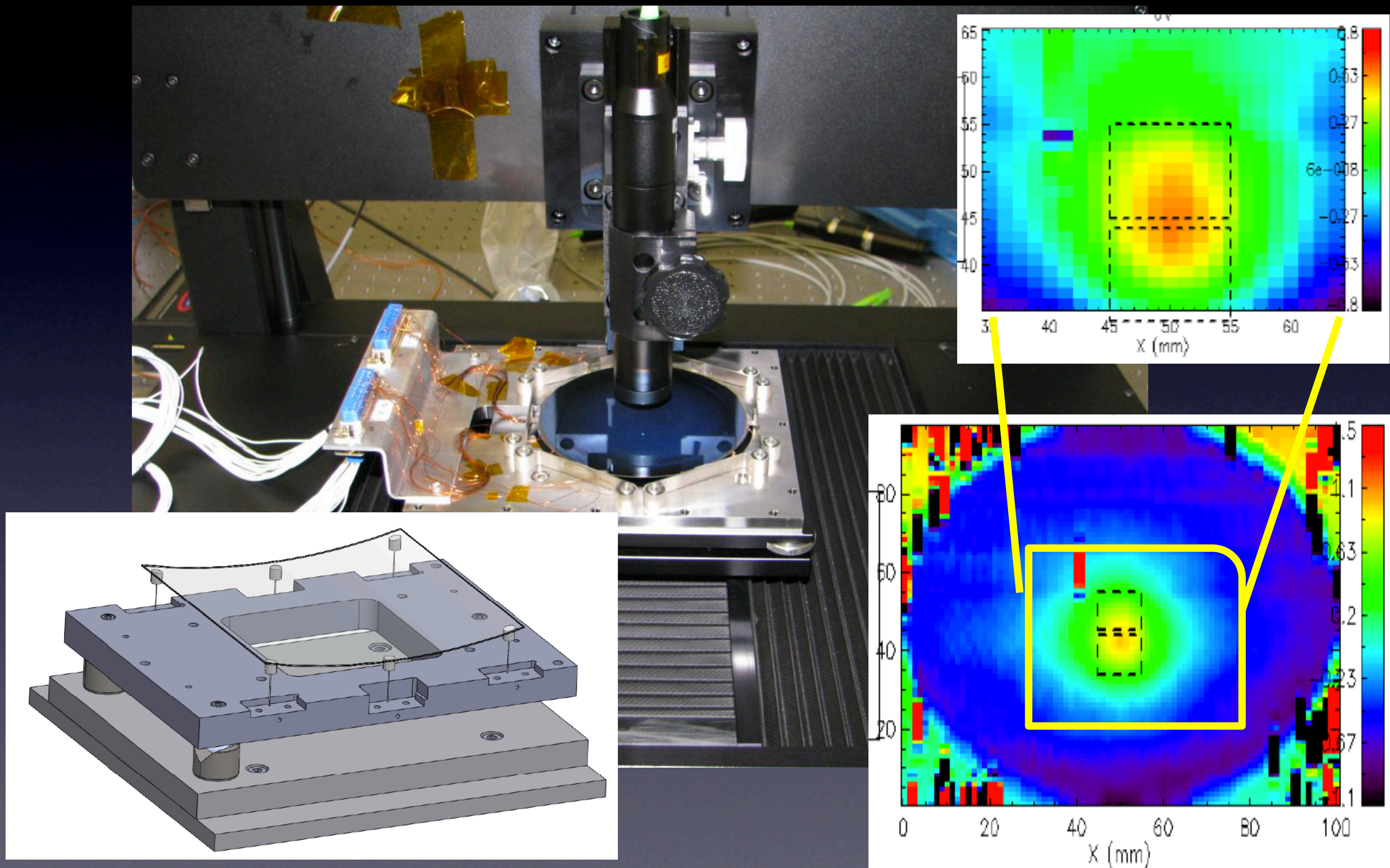


Energizing PZT cells produce repeatable deflections



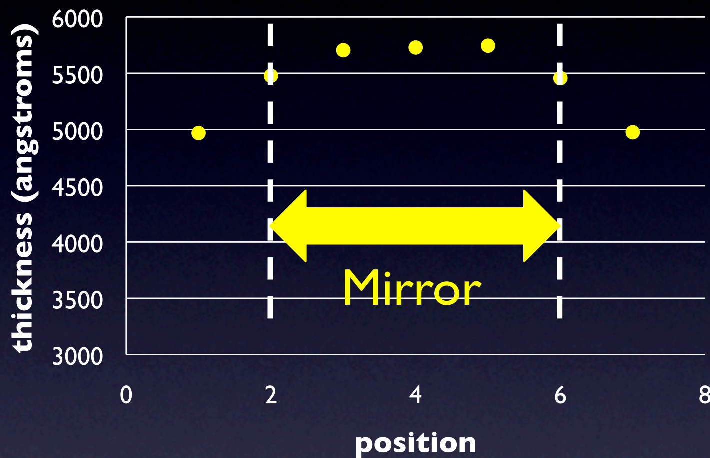
Small tick mark division = 50 nm
Metrology accuracy ~ ± 50 nm

Incorporating new, higher accuracy, lower noise metrology capable of measuring conical mirrors



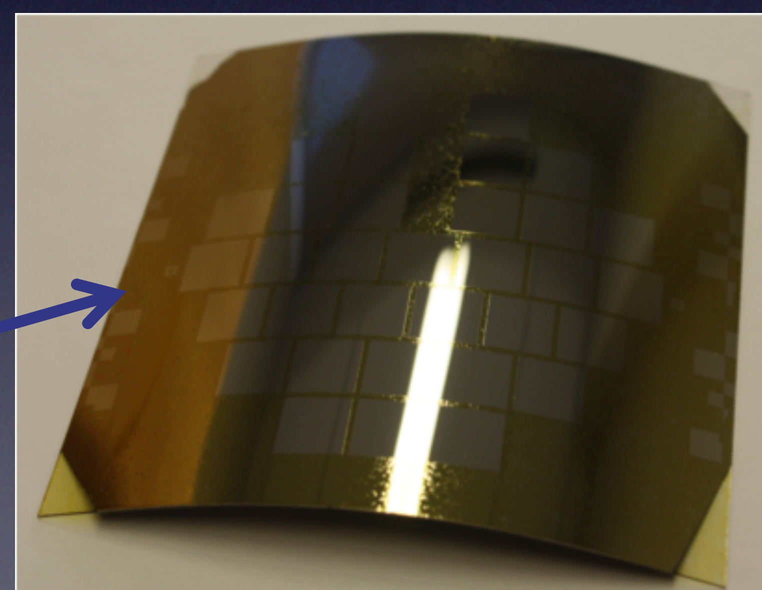
Deposition and Patterning on conical/cylindrical mirrors

- Deposition Uniformity
  - Requirement: ≤10 per cent (each PZT cell separately calibrated)
  - Recent results with witness samples, 2 sputter guns



5 per cent over mirror aperture
(white dashed lines, left)

- Electrode patterning



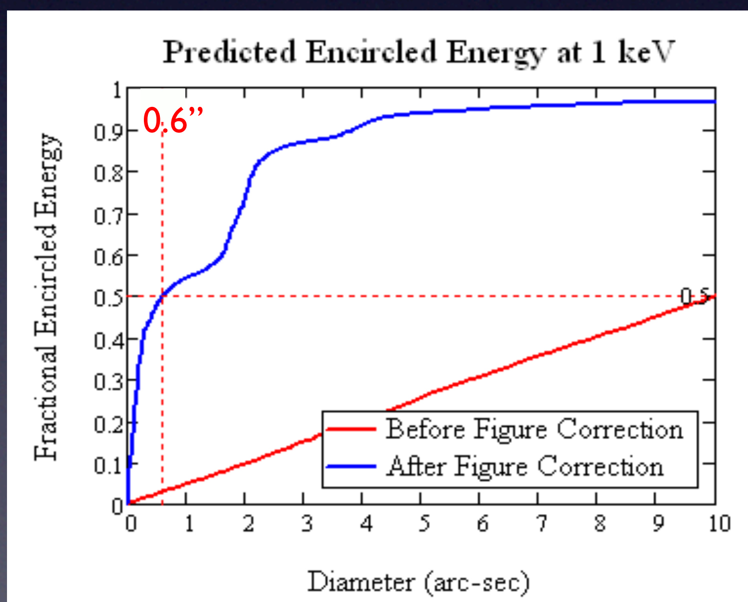
Simulated correction of measured data yields 0.6 arc sec HPD for initial 10 arc sec mirror pair

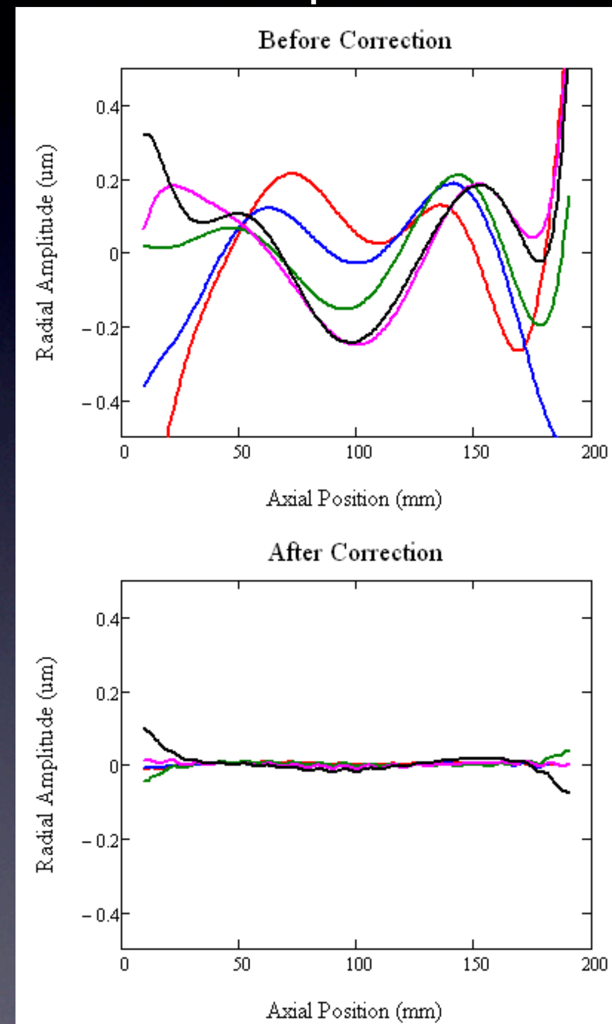
Use modeled influence functions for SMART-X mirror to correct representative data:

‘Before Correction’ = interferometer measurement of mounted IXO mirror (ca. 2008).

‘After Correction’ = residual after least squares fit of ~ 400 influence functions.

Compute PSF using full diffraction calculation:





Expect that correction of current AXSIO 7″ mirrors produced at GSFC will meet SMART-X goals.

Our technology development path

- TRL 2: technology concept
  - Demonstrate PZT can be deposited and works on flats ✔
  - Deterministic (models agree with experiments) ✔
- TRL 3: experimental demo of critical function
  - Demonstrate PZT can be deposited and works on cylindrical pieces – *in process*
  - Deterministic – *follows after demonstration*
  - Simulation demonstrates feasibility ✔
- TRL 4 (proposed): breadboard validation with Wolter-I mirrors
  - Mount and align mirror pair to 0.25 arcsec in a "flight-like" mount
    - "flight-like" = survive launch loads and G-release
  - Correct figure errors of mounted aligned mirror pair to 0.5 arcsec HPD after accounting for test configuration errors
  - Demonstrate/verify with X-ray test

Multiple On-going and Planned Activities

- Demonstrate deposition of PZT and electrodes, and deterministic performance, on cylindrical substrates (TRL3).
- Incorporate new, higher accuracy metrology.
- Model impact of piezo cell failure on imaging performance to determine piezo lifetime requirements / prob of failure.
  - Accelerated and real-time lifetime testing
- Continue yield/uniformity enhancement via process and doping.
- Optimize shape/size of influence functions.
  - Improve correction efficiency and bandwidth
- *Examine command and control electronics for piezo cells*
  - *integrated on-cell electronics and row/column addressing*
- *Build aligned, mounted Wolter-I mirror pair, correct figure, and X-ray test (TRL4, 2015).*

Technology Status Summary

1. Technology builds upon IXO / AXSIO optics technology development.
2. PZT thin films can be deposited on glass, work as piezos, and meet requirements.
3. Approach is deterministic: demonstrated good agreement between modeled and measured influence functions.
4. Patterning of electrodes and uniform deposition on curved mirrors demonstrated.
5. Approach is consistent with half-arcsec imaging: simulations show correction of ‘old’ [IXO 2008] 10″ HPD mounted mirror pair to 0.6″ HPD. Expect current GSFC 7″ AXSIO mirrors correctable to 0.4″.
6. A technology development plan exists, leading to TRL4 in 2015 and TRL6 in 2019.