SAO

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

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New technology is needed for large area, high-resolution X-ray telescopes

Limitations of existing technologies:

•*Chandra* approach (precisely polished mirrors):

- Thick mirrors necessary for polishing result in too heavy a telescope (20,000 kg/m^2)

•Replication approaches (IXO/AXSIO, XMM...) and pore optics (IXO/Athena)

- Resolution too coarse by a factor of >10–20

New technical approach — adjustable bimorph mirrors:

•Use replication technologies to enable large collecting area

- Build upon extensive IXO heritage in mirrors, alignment, mounting

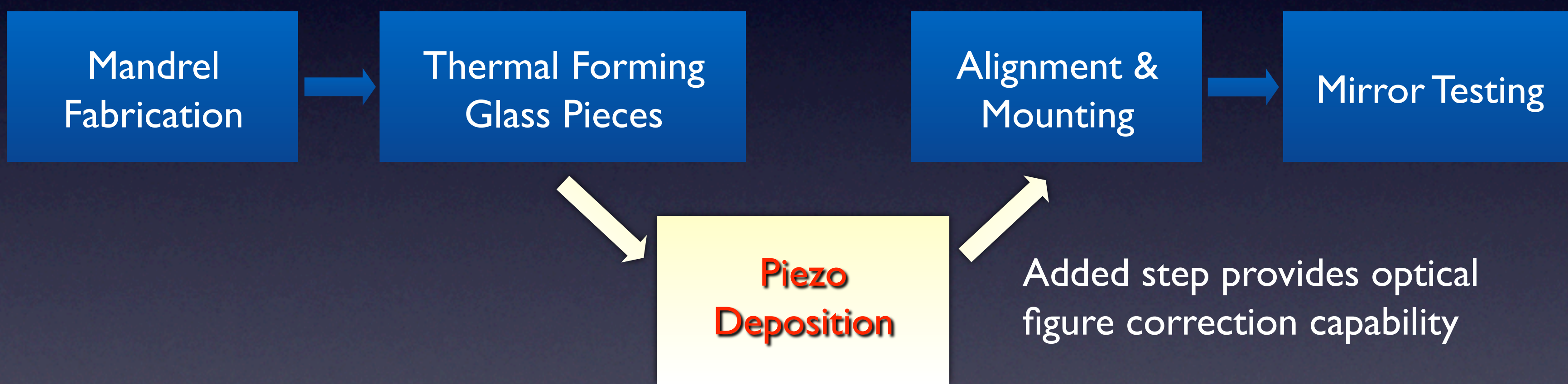
•Difficult to achieve and maintain precise figure with thin mirrors, so…

•Make mirror figure adjustable after mounting

- Enable correction of 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

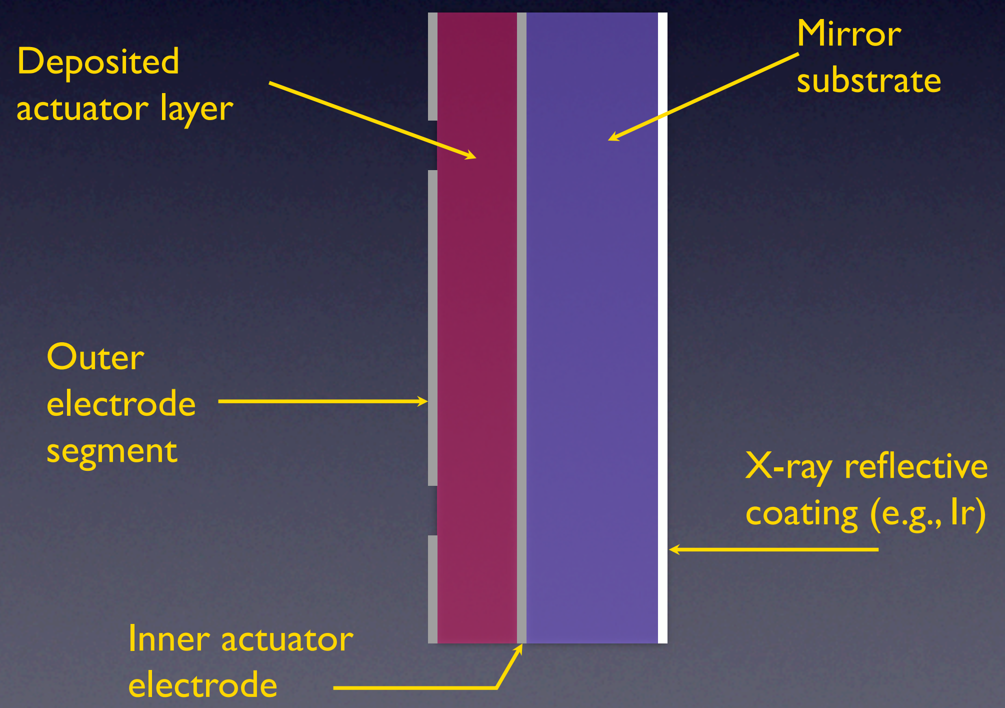


Adjustable optics technology development funded by multiple sources:

•NASA APRA, SAO IRAD and SAO labor, and the Gordon and Betty Moore Foundation

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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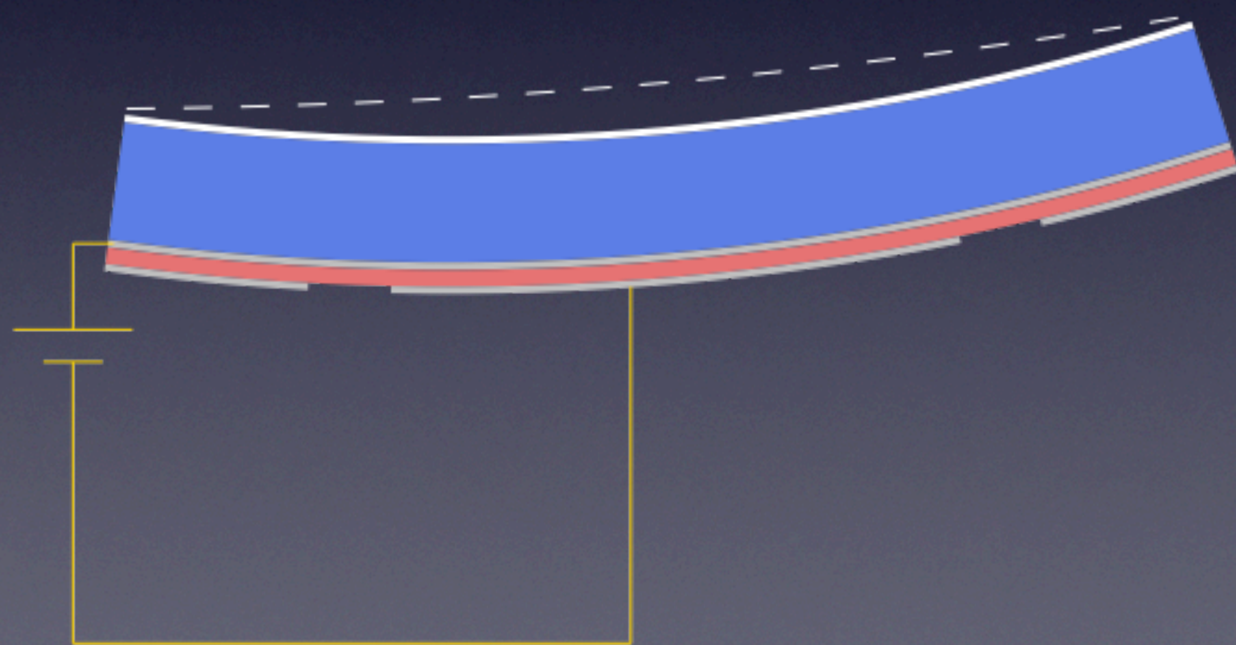

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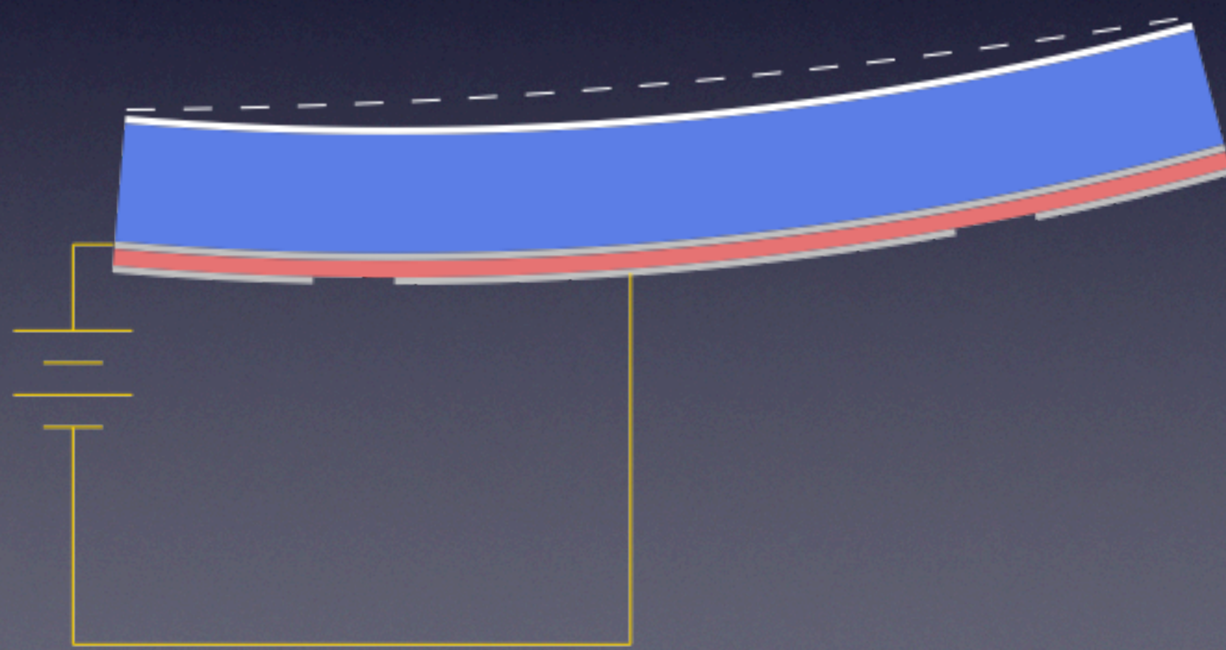

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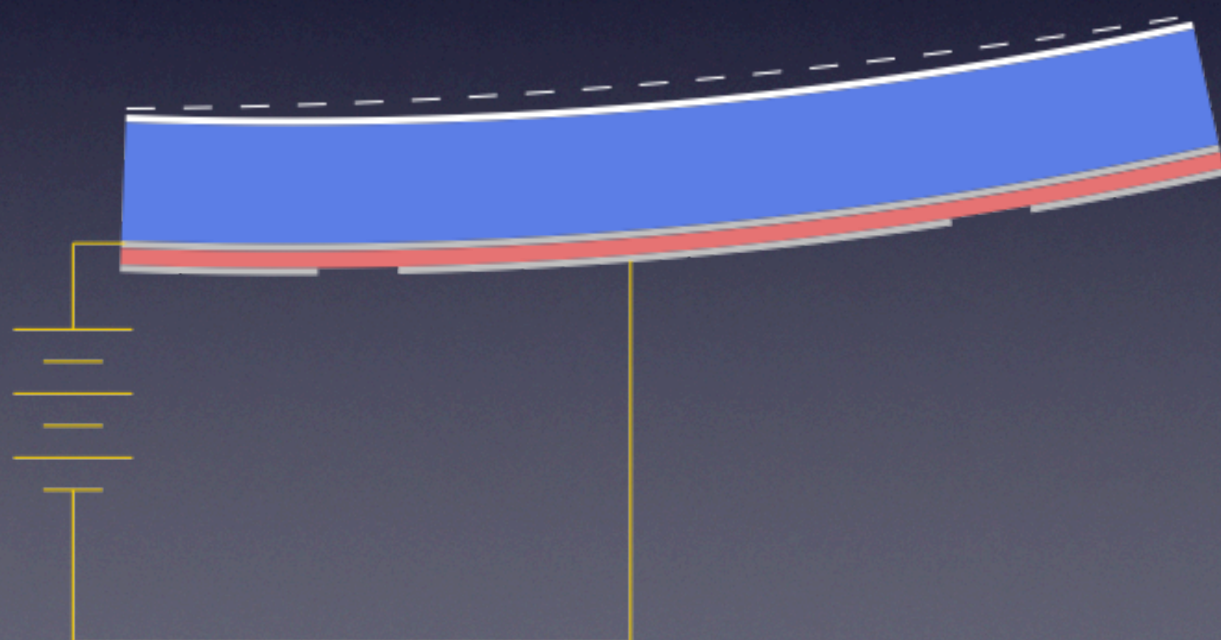

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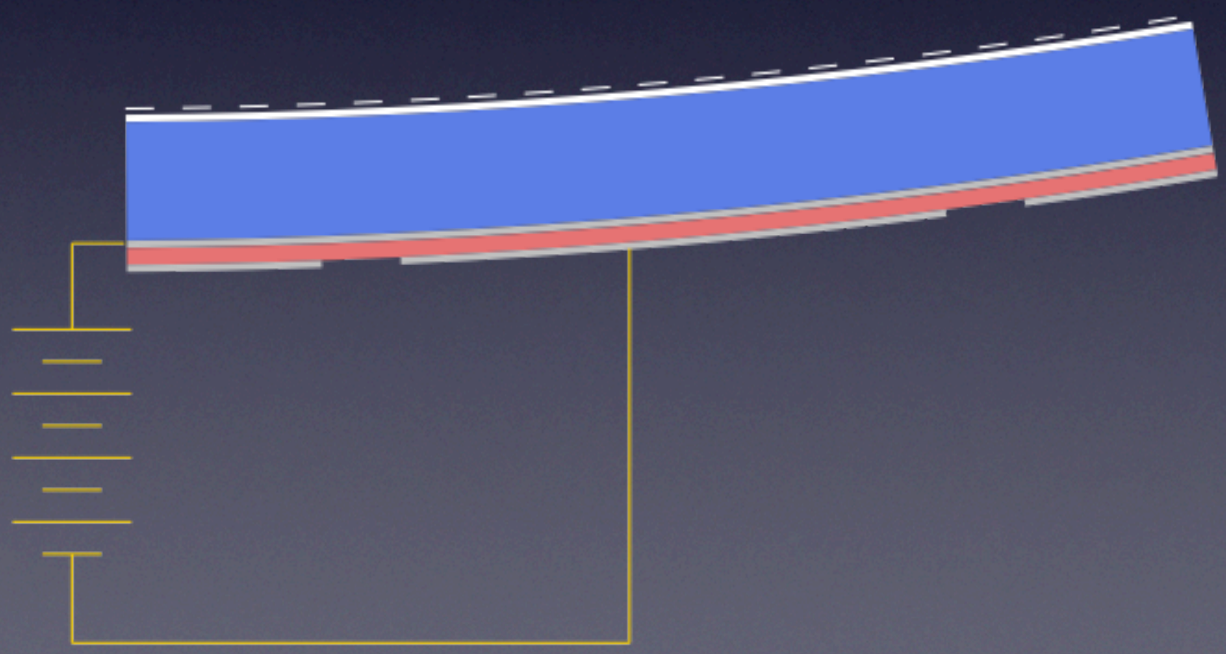
- Optimize the voltages for each piezo cell to minimize the figure error in the mirror.



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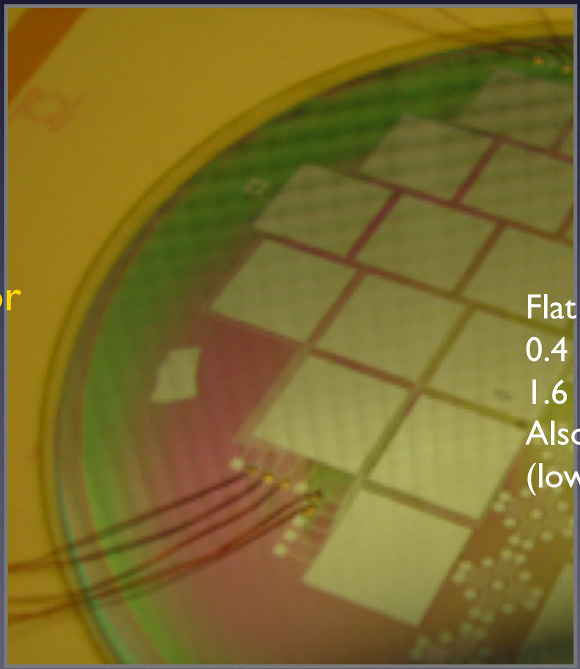
Major accomplishment:

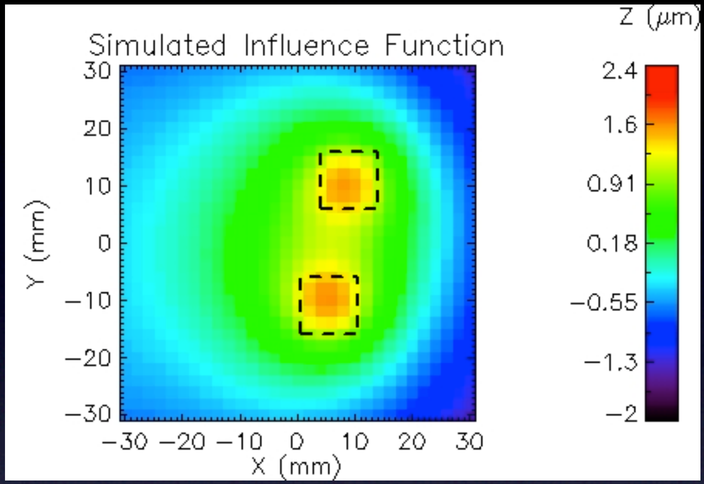
•Deposition of piezos on glass (Penn State Materials Lab).

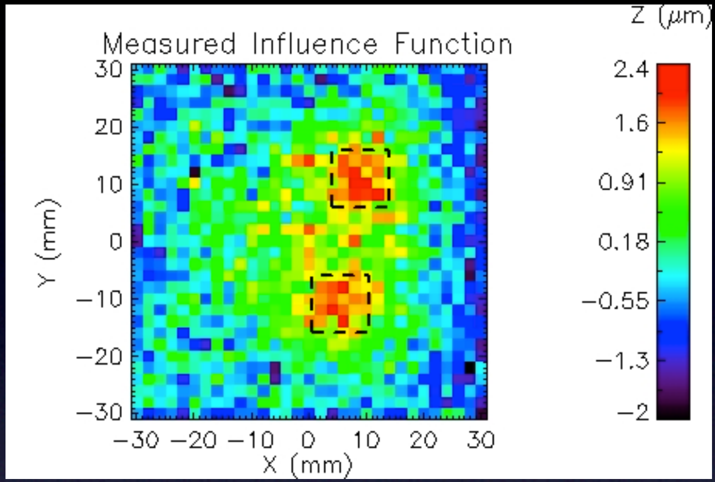
•First time PZT deposited on glass for such large areas.



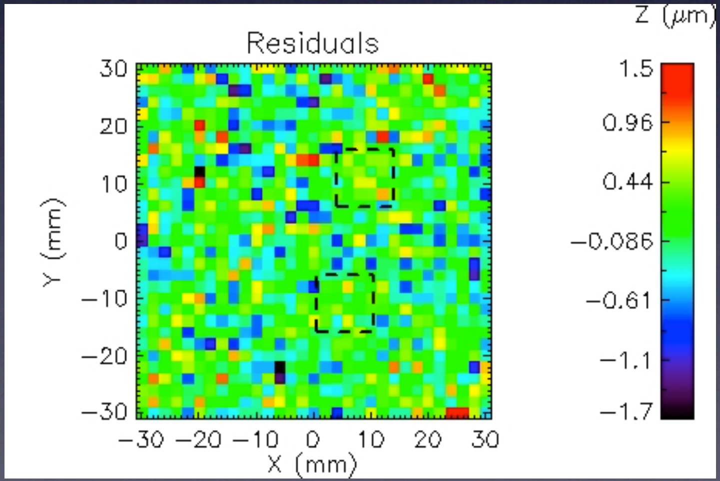
Flat test mirror – 100 mm diameter
0.4 mm Corning Eagle glass with
1.6 μm PZT and 1 cm^2 electrodes
Also shows pattern of strain gauges
(lower right) deposited on PZT.

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.



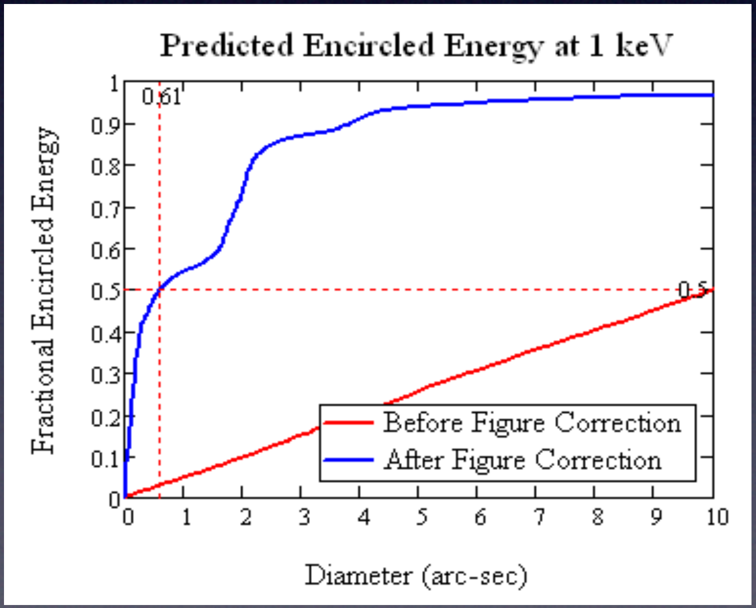
Simulated correction of measured data yields 0.6 arc sec HPD for initial 10 arc sec mirror pair

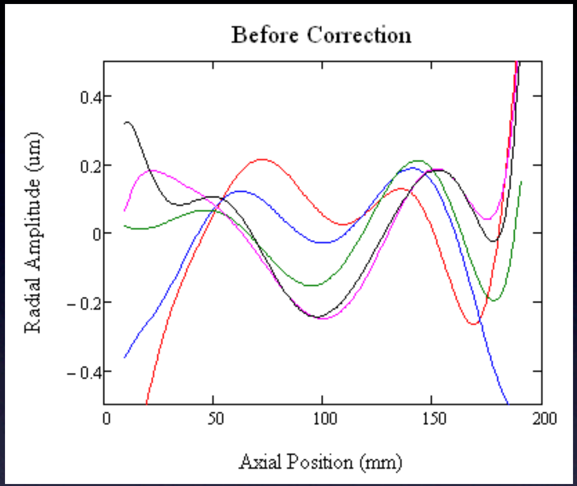
Use modeled influence functions for SMART-X mirror to correct representative data:

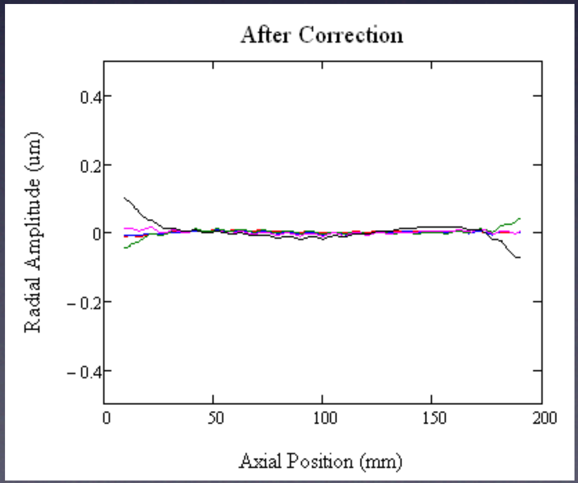
'Before Correction' = interferometer measurement of mounted IXO mirror (ca. 2008).

'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.

TRL definitions and status

- 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/conical pieces – *in process*
  - Deterministic – *follows after demonstration*
  - Simulation demonstrates feasibility ✔
- TRL 4 (proposed): breadboard validation
  - Mount and align sub-scale 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

Current 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 perfomance to determine piezo lifetime requirements / prob of failure
- Accelerated and real-time lifetime testing
- Optimize shape/size of influence functions

- Examine command and control electronics for piezo cells
  - integrated on-cell electronics and row/column addressing
- Develop mounted aligned mirror pair for X-ray testing (TRL4, 2015).

Extendable to normal incidence Active Optics (AO)

- Current AO approaches have limitations
  - "voice coils": vibration, high power, cooling, mass
  - Ferro-electric "push-pull": actuator density in pupil plane, mass
  - MEMs: tertiary deformable mirrors (DMs) in the system
- Thin film piezo bimorph mirrors may address these issues:
  - Low power (<10 watts/million adjusters)
  - Low driving mass
  - High density
  - No need for tertiary optics
- Suitable for space-based observatories
  - Large area and light weight
  - UV/VIS/NIR

Technology Status Summary

1. Technology builds upon IXO/AXSIO optics technology development.
2. Piezoelectric thin films can be deposited on glass, work as piezos, and meet piezoelectric requirements.
3. Approach is deterministic: demonstrated good agreement between modeled and measured influence functions.
4. 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 can be corrected to 0.4″.
5. A technology development plan exists, leading to TRL4 in 2015 and TRL6 in 2019.