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Upgrading Wolter Imagers for X-Ray Diagnostics in the Z Pulsed-Power Facility at Sandia National Laboratories

J. K. Vogel, B. Kozioziemski, C.C. Walton, J. Ayers, P. Bell, D. Bradley, M.-A. Descalle, S. Hau-Riege **(LLNL)**
J.R. Fein, D.J. Ampleford, C.R. Ball, P.D. Gard, M. Jones, A. Maurer, M. Wu **(SNL)**
P. Champey, J. Davis, C. Griffith, J. Kolodziejczak, B. Ramsey, J. Sanchez, C. Speegle, M. Young **(NASA MSFC)**
K. Kilaru, O. J. Roberts **(USRA)** & A. Ames, R. Bruni, S. Romaine, L. Sethares **(SAO)**

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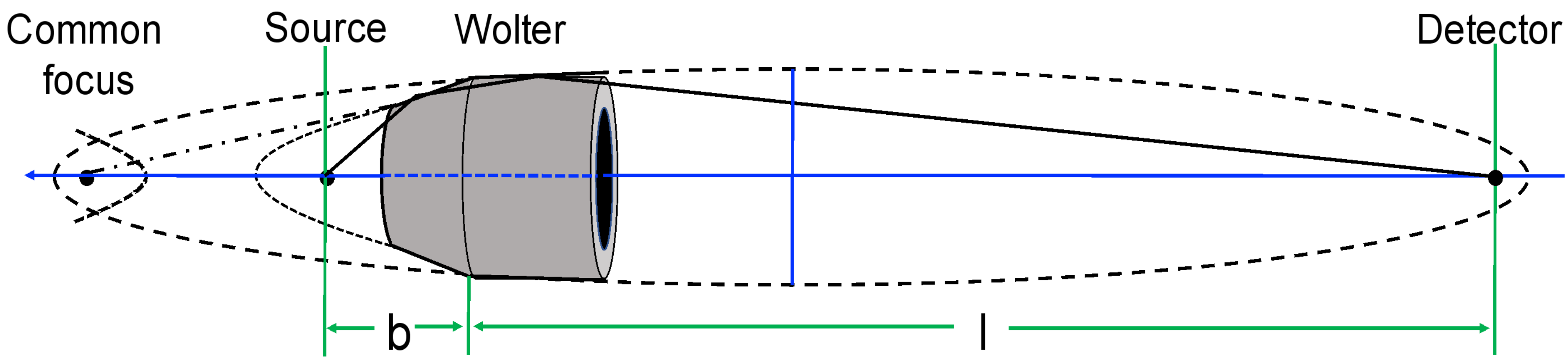
Operation Principle of Wolter Optics

- Three families of designs, nestable version (Wolter I) most widely used
- Wolter I has properties similar to a thin lens
- Wolter design addresses two challenges of grazing-incidence optics
  - Nested designs allow for increased collecting efficiency
  - Two conic surfaces of revolutions nearly satisfy Abbe sine rule reducing strongest aberration contributions



Major advantages of Wolters include:
large solid angle, large field of view (FoV), large throughput

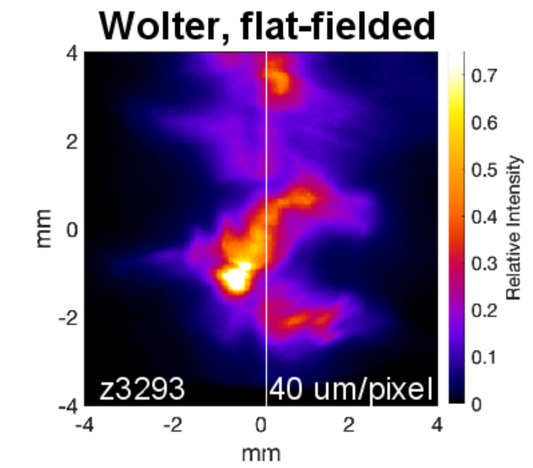
Z-Wolter Optics Performance

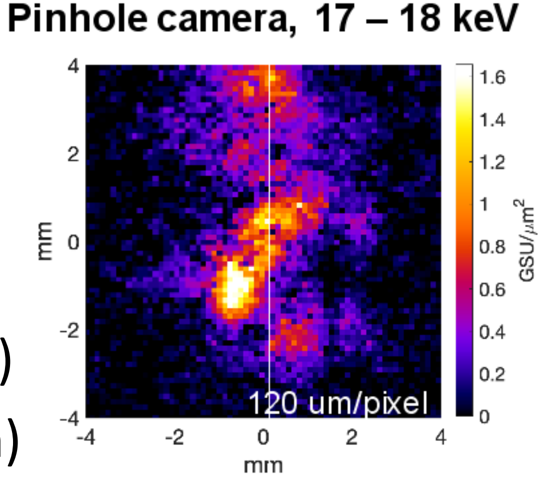
Wolter imager successfully fielded in SNL's Z machine

- K-shell emission data using Mo wire arrays (~17.5 keV) demonstrated superior imaging capability over large field of view (5×5mm^2) enabling in-depth study of these sources
- Improvement in signal of factor 100-1000 compared to pinhole camera image in same E-range
- Wolter optic reveals features of order < 200 μm

Extending Wolter applications for future experiments

- Temporally-resolved imaging (photon starvation)
- Higher energies (dimmer sources/need high reflectivity R)
- Better spatial resolution (challenges for optics fabrication)





Next generation of Wolter imaging diagnostics requires high throughput and ideally further improved spatial resolution (< 50 microns)

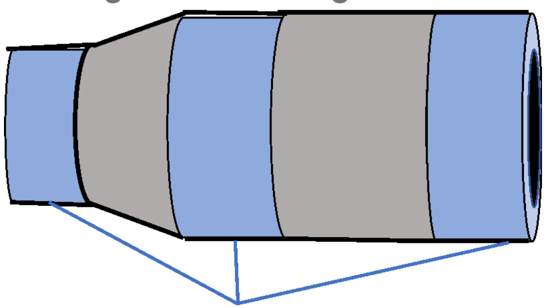
Improvements for Next-Gen Wolter Optics

1) Fabrication of High-Precision Mandrel

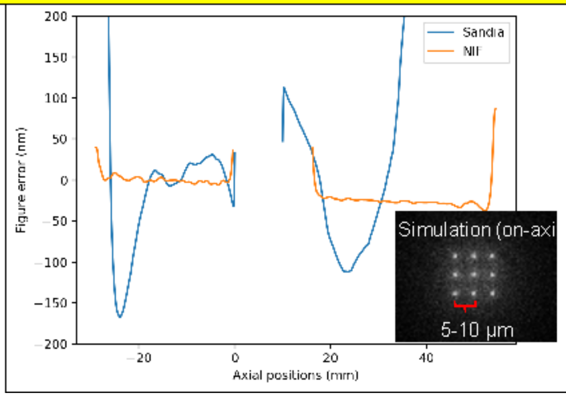
- Design improvements for mandrels: flat segments added to mitigate performance-degrading end-effects
- Polishing procedure improved to produce more consistent surface: Upgraded polishing slurry & alignment procedure for sub-aperture polisher (Zeeko)

  → 2× decrease in figure error & reduced process time
- MSFC IXPE (Imaging X-ray Polarimetry Explorer) optic required improved lap polishing directly benefitting NIF/Z Wolter

  → Error introduced during polishing reduced by a factor of ~5 with new process
- Improvements enabled fabrication of test mandrel meeting NIF figure requirement to achieve <5-10 μm resolution over 1 mm FoV (10× reduction in figure error)



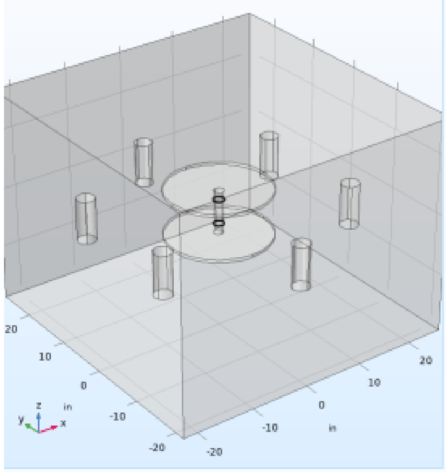
Optical profilometer measurement of mandrel figure error for 1st gen Z-Wolter and 2nd gen NIF-Wolter



Improved Lap polishing and Zeeko able to maintain figure and roughness to provide mandrel expected to produce shells for <50 μm spatial resolution on Z

Improvements for Next-Gen Wolter Optics

2) Advancing Replication Technology



- Improved fast (<1h/shell) metrology setup using IXPE assembly station
  - Shells suspended from 3 wires
  - Enables measurements along length of shell and multiple azimuthal positions
  - First results indicate end-effect deformations restricted to flat pieces (4-8 μm peak-to-valley); optic largely unaffected

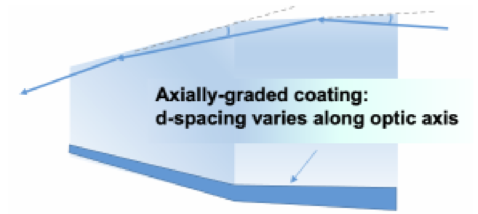
- Comsol 3D simulations of replication bath to determine key factors to improve deposition uniformity
  - Geometric dimensions
  - Electrolyte conductivity
  - Gasket configuration and copper tape usage
- Replication tests planned to verify model predictions
- Plans to include effects causing non-symmetric azimuthal variations

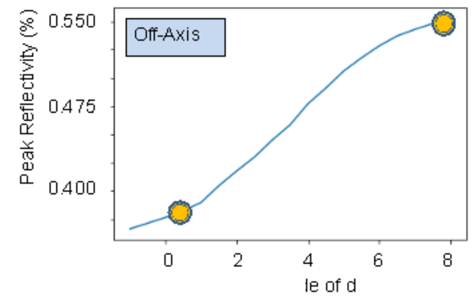
Focus on improving replication process to keep additional figure error contributions from replication and release small and use full potential of mandrel

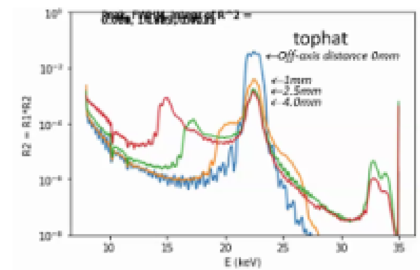
Improvements for Next-Gen Wolter Optics

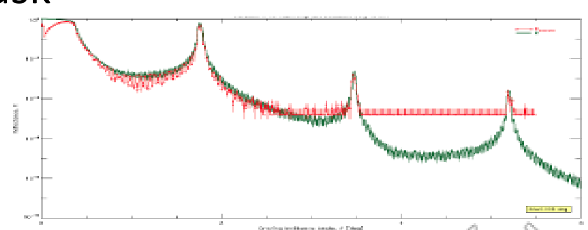
3) Boosting Multilayer Reflectivity

- Optimization of multilayer (ML) recipes using evolved search algorithms for constant d-spacing, multiple-stack and depth-graded designs
  - Study showed axial ML grading of about 6% could further increase reflectivity by 1.4×
  - Optimization for best performance and maximal flexibility: highest reflectivity, flat response, optimal rejection of photons outside of spectral ROI (non-thermal vs thermal)
- Advancing multilayer deposition process
  - Push reflectivity by increasing number of deposited layer pairs via higher operating current of coater
  - Improvements to coating uniformity possible using coating mask
  - Exploring additional options to boost reflectivity
    - Use of alternative ML material systems
    - Reactive sputtering to increase R and reduce stress









Conclusions and Outlook

- Wolter optics successfully employed in SNL's Z-machine:

  Improvement in signal-to-noise of factor ~10-30 compared to current best diagnostic and reached 60-300 μm spatial resolution (previously 900 μm)
- Pushing technologies to higher spatial resolutions (<50 μm for Z, <5-10 μm for NIF) with R&D on mandrel fabrication and polishing as well as replication
- Implementation of time-gated imaging has highest priority together with longer-term goal of pushing Wolter application towards higher energies both require boosting the reflectivity

For more information please attend Jeff Fein's invited talk:
High-resolution imaging of warm x-ray sources with a Wolter optic on the Z Machine
or feel free to contact me (vogel9@llnl.gov)

THANK YOU FOR YOUR ATTENTION!
QUESTIONS?

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