Wolter Imaging On Z

Chris Bourdon, Manager Z Imaging and Spectroscopy
Julia Vogel, LLNL; Ming Wu, SNL
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K-\(\alpha\) emission from z pinches can provide >15 keV x-rays for Radiation Effects Science – Where do these x-rays originate?

Non-thermal processes (cold K-\(\alpha\)) become more efficient at >15 keV

Spectra show cold K-\(\alpha\) from a large area, but structure is complex

- Thermal Emission
- Non-Thermal Emission

Yield (kJ) vs. Photon Energy (keV)
## Monochromatic Kα imager needs

<table>
<thead>
<tr>
<th>Need</th>
<th>Goals</th>
<th>Driver</th>
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</thead>
<tbody>
<tr>
<td>Photon energies (Kα’s)</td>
<td>Mo: 17.479 keV</td>
<td>Study K-shell radiators from Ag to W</td>
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<td></td>
<td>Ag: 22.163 keV</td>
<td>Also: Off line-center? (L-shell state)</td>
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<td>W: 59.318 keV</td>
<td>He-α?</td>
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<td>Spectral window</td>
<td>~1 keV</td>
<td>Simultaneously view K-alpha 1 &amp; 2 from cold and low-ionization states</td>
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<td>Field of view</td>
<td>+/-12 mm</td>
<td>Collect all emission from 2 cm pinch.</td>
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<td></td>
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<td>Kα emission comes from large diameter</td>
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<tr>
<td>Spatial resolution</td>
<td>0.1 mm desirable; 0.25 mm required</td>
<td>Resolve length-scale of structures emitting Kα</td>
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<td></td>
<td></td>
<td>(don’t know what these are)</td>
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<tr>
<td>Time resolution</td>
<td>Time integrated OK initially ~1 ns in 3-5 years</td>
<td>Resolve evolution over pulse</td>
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<td>Sensitivity</td>
<td>100 J from ~cm^3 source with good signal to noise</td>
<td>Able to record 100 J over full source area</td>
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<td>Calibration</td>
<td>Relative response at image plane known to &lt;10%</td>
<td>No need for absolute calibration</td>
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### Other considerations
- Survivable (optic at >40 cm from source)
- Hard x-ray background (1-inch W in LOS)
- 0 degree view (detector <300 cm from source)
A mag = 3 Wolter microscope would go along a 0-degree port on the Z target chamber with the optic ~75 cm from the source.

This is a geometry very similar to what has been previously demonstrated with multi-layer Wolters.
The development roadmap has the first Wolter system fielded on Z in FY17 with time-resolved versions on Z and NIF in FY19.

- Manufacture and test multi-layer Wolter optic for Z before beginning significant design for NIF.

- hCMOS at 20-40 keV comes available in FY18-19.

<table>
<thead>
<tr>
<th>Wolter Microscope</th>
<th>FY15</th>
<th>FY16</th>
<th>FY17</th>
<th>FY18</th>
<th>FY19</th>
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<tr>
<td>Z Tasks</td>
<td>NASA Contract Placement</td>
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<td>CDR</td>
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<td>Wolter Manufacturing</td>
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<td>Development of Calibration Capabilities</td>
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<td>Optic Testing</td>
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<td>Design of Optic Alignment Assembly</td>
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<td>Design of Detector (Time-integrated)</td>
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<td>IDR</td>
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<td>FDR</td>
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<td>Manufacturing</td>
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<td>Commissioning</td>
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<td>Integration of H-CMOS detector</td>
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<td>NIF</td>
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- Manufacture and test multi-layer Wolter optic for Z before beginning significant design for NIF.
- hCMOS at 20-40 keV comes available in FY18-19.
Why a Wolter?

- Requirement is for large FOV (so no kB)
- Can de-couple resolution from effective collection area
- Custom tailoring of x-ray spectral bands
- Comparison with a Pinhole:
  - For same magnification and detector plane:
    - ~2mm pinhole to maintain same number of photons on detector
      - Resolution insufficient
    - To maintain resolution, 400X decrease in signal
      - SNR insufficient
  - To maintain similar resolution and signal level on detector: 100-micron pinhole; detector 35 cm from load (pinhole 23 cm), assuming equivalent filter efficiency.
    - Detector survivability an issue, facility integration much more challenging, higher background
### Parametric design space for SNL Wolter Optic

**Case A1-A8 (Mo)**
- **M** = 3/4
- **D** = 2.54/2.92/3.05 m
- Mirror length (**L_H**) = 30/40 mm
- **θ_i** = 1.33°
- FoV ≈ ±10 mm
- η ≈ 10^{-5}

**Case B1-B8 (Ag)**
- **M** = 3/4
- **D** = 2.54/2.92/3.05 m
- Mirror length (**L_H**) = 30/40 mm
- **θ_i** = 1.05°
- FoV ≈ ±10 mm
- η ≈ 10^{-5}

**Case C1 (Mo)**
- **M** = 4
- **D** = 3.00 m
- Mirror length (**L_H**) = 20 mm
- **θ_i** = 0.47°
(Suzanne’s parameters)

**Parameters for case A and B are similar, but currently optimized for corresponding energy**

**Note:** all curves are “ideal curves”, i.e. no figure error, ML included
Resolution (HPD) versus distance from optical axis

Mo (17.75 keV)  
M = 3

Ideal curves—does not include figure error

Resolution (object plane), mirror length
Resolution (HPD) versus distance from optical axis

- Ideal curves—does not include figure error

- Pre-prototype optic
- $L_H=20\text{mm}$
- $D=3.00\text{m}$

- Mo
- Ag
Resolution (object plane)

Preferred design Mo (A3)

| HPD (microns) | 8e-05 | 1.1 | 3.3 | 7.1 | 12.4 | 19.2 | 27.9 | 37.4 | 48.6 | 61.7 | 75.4 |

Idealized image—does not include figure error

Preferred design Ag (B3)

| HPD (microns) | 8e-05 | 1.0 | 3.9 | 8.7 | 15.4 | 24.0 | 34.6 | 46.4 | 60.5 | 76.8 | 93.1 |

Pre-prototype (C1)

| HPD (microns) | 8e-05 | 2.9 | 11.2 | 24.9 | 43.7 | 63.5 | 87.5 | 116.4 | 149.8 | 192.4 | 237.0 |
Wolter Optic calibration

- The calibrations are needed to determine throughput and resolution as functions of x-ray energy and off-axis angles
- Initial calibration at synchrotron light source (APS)
- Develop in-house calibration facilities (LLNL and SNL)
- X-ray source requirements: energy (15-100 keV), flux ($\sim 10^6$ photons/sec$^{-1}$mm$^{-2}$), and beam size (10s mm for SNL)
- High precision rotation and translation stages for Optics: three-axis rotations, ($0.001^\circ$) and two-axis translations ($\sim 1\mu$m)
- Hard x-ray imaging detectors: CCD-based hard x-ray imager
Shock and debris pose major challenges

- Wolter Multilayer Optic will sit ~76 cm from the pinch
  - Protecting from debris damage and soot deposition critical
  - Plan is to use heavy filtering and hermetic sealing of optic to protect it
    - 3 X 0.5 mm aluminized Kapton on front, 1X0.5 mm on back
    - Sintered filter on vent port

- Significant experience with other diagnostics (CRITR, TIPC) at similar or nearer locations using this methodology

- Promise shown with other protection schemes for large-format imagers (XRS3; UHD polymers)

- Strategy will be to protect the optic, but make the alignment stage low-cost, potentially disposable
Optic Alignment Tolerance and Alignment Strategy

- Alignment requirement based on:
  - optic performance simulation
  - angular misalignment will be similar to thin lens
- R, Z, Theta of optic: +/- 1 mm acceptable
- Angular alignment +/- 2 miliradians

- Alignment logistics:
  - Retro-reflectors on back of optic
  - Visible laser to define optical path, angular alignment of optic
  - Motorize alignment to enable alignment from diagnostic boat and while under vacuum
Detector

- **Image Plate**

  ![Graph](image1.png)


- **H-COMS:1** - 2 ns gate time, 8-frame, FY18)
  - 3-D diode approach
  - High Z material, Ge or GaAs

![Graph](image2.png)

![Graph](image3.png)
Summary

- Initial studies show it’s feasible to meet the science objectives for measuring cold k-alpha emission on Z with a Wolter microscope
  - Simulations of resolution (HPM) meet requirement
  - Estimated reflectivity and spectral window promising
  - Alignment tolerances achievable
- Implementation appears to be straightforward
  - Debris mitigation feasible
  - Alignment requirements do not require complex implementation
  - Time-integrated detector trivial (image plate), time-gated depends on hCMOS development of a high-energy (20-60 keV) sensor in FY18