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A Wolter Imager on the Z Machine to Diagnose Warm X-ray Sources

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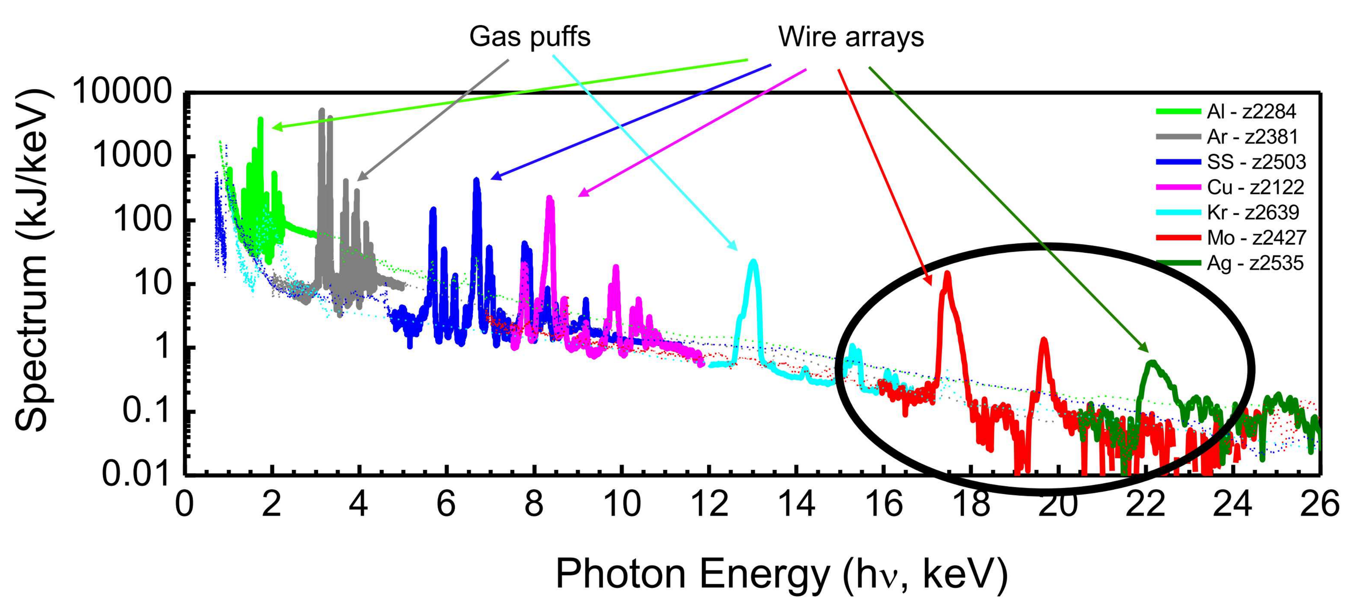
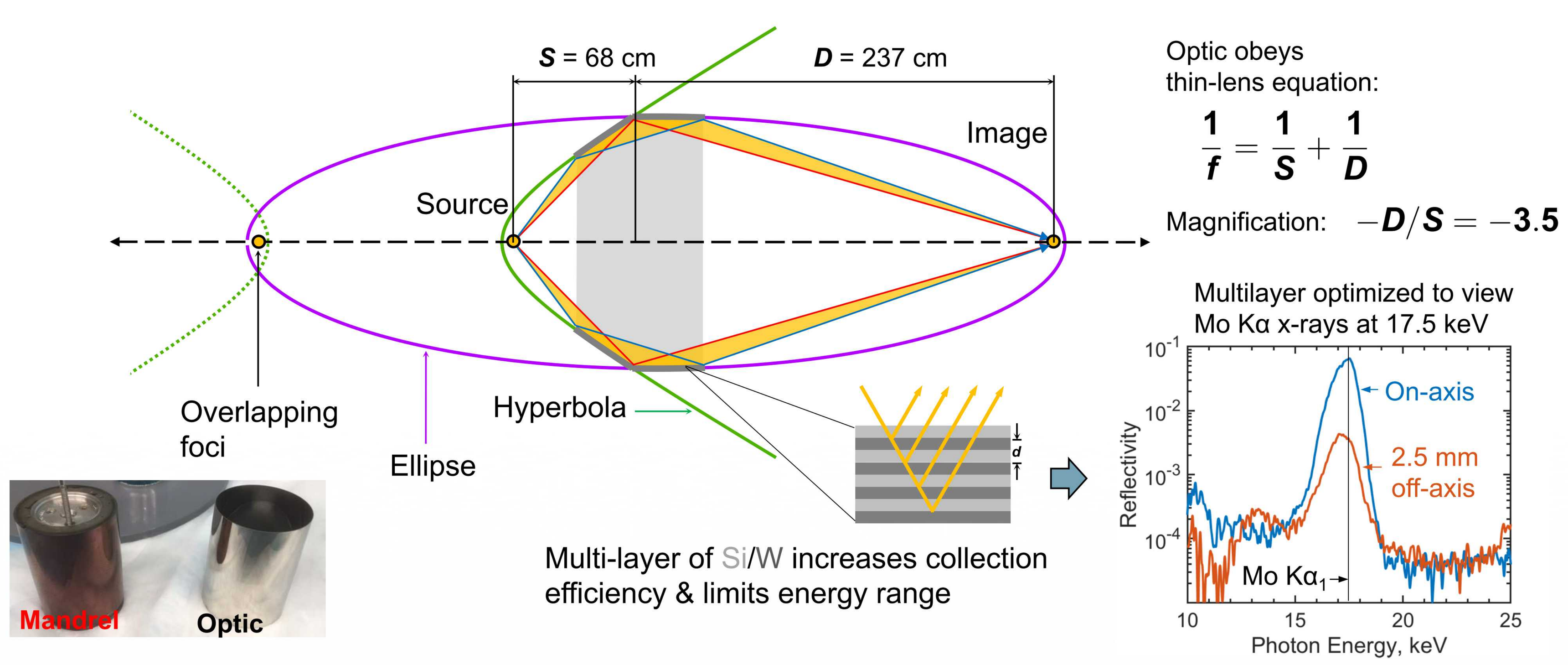
The study of warm (>15 keV) x-ray sources[1] requires imaging capabilities with greater efficiency than previously achievable



- We are developing *Non-thermal wire arrays* as >15 keV x-ray sources[1]
- The ability to image >15 keV sources was previously limited[2] by poor resolution (~1mm) and low signal/noise (~3)
- ***Wolter optics***,[3] adapted from observational astronomy and the medical field[4] are a promising option for high-resolution and high-contrast imaging of warm x-ray sources with large (>5 mm) fields-of-view (FOV):



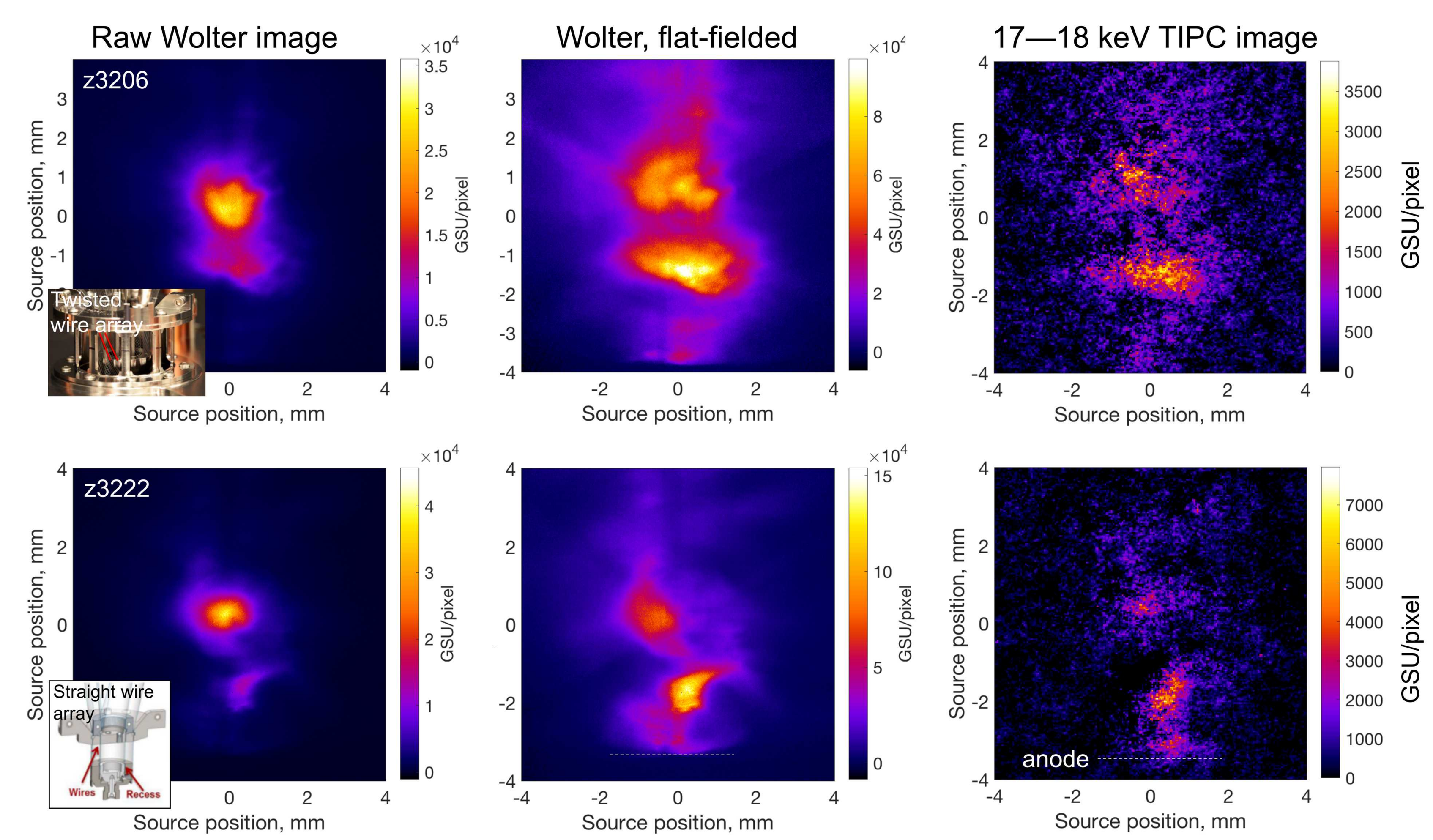
Wolter optic imager provides several advantages over traditional pinhole cameras:

- Tunable band-pass enables quasi-monoenergetic imaging
- Higher collection efficiency from focusing geometry and multilayer
- Large stand-off distance allows for compatibility with hCMOS detectors,[5] providing time-resolved imaging

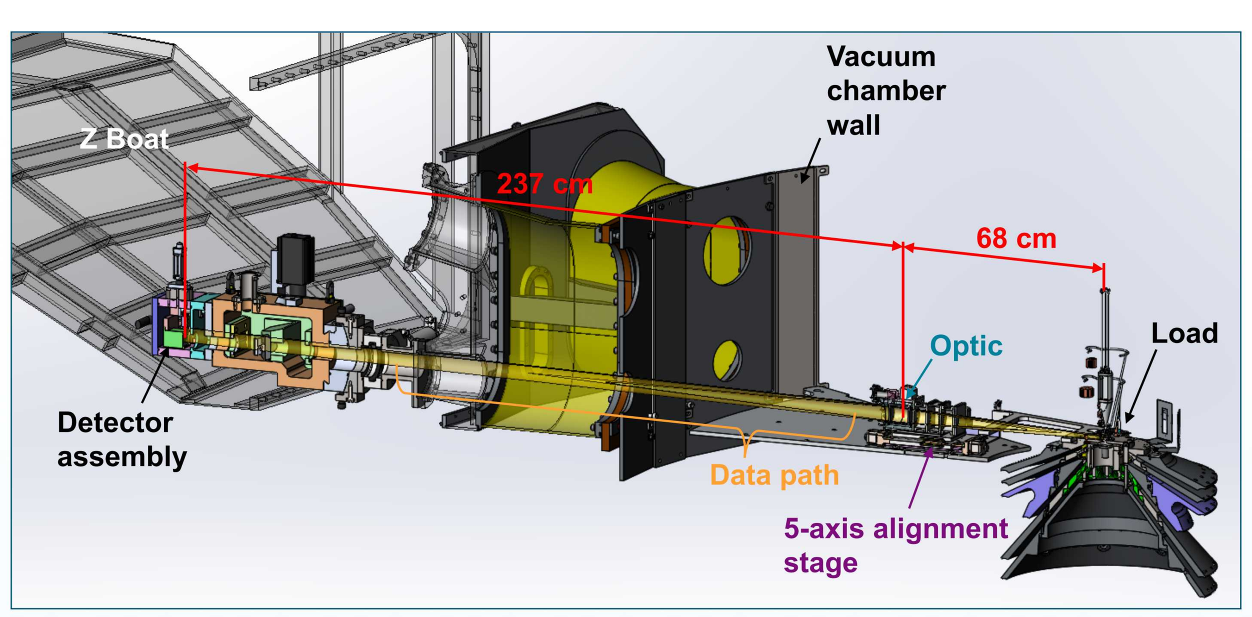
References

1. D.J. Ampleford *et al.*, *Physics of Plasmas* **21**, (2014)
2. L.A. MacPherson, *et al*. *Rev. Sci. Instrum.* **87,** (2016)
3. H. Wolter, *Ann. Physik* **10**, (1952)
4. Pivovoroff, et al., *Proc. SPIE,* **5923** (2005)
5. L. Claus, *Proc. SPIE*, **9591** (2015)
6. L. Denis, et al., *Int. J. Comput Vis.* **115** (2015)

Wolter was successfully fielded on the Z Machine, acquiring images of Mo wire arrays



- Raw Wolter images are flat-fielded by dividing by the throughput over the FOV
- Flat-fielded Wolter images have features similar to those seen in TIPC[2] images
- Wolter demonstrates spatial resolution better than 150 microns, compared to ~1 mm in TIPC, as well as a factor of >3 increase in the signal/noise



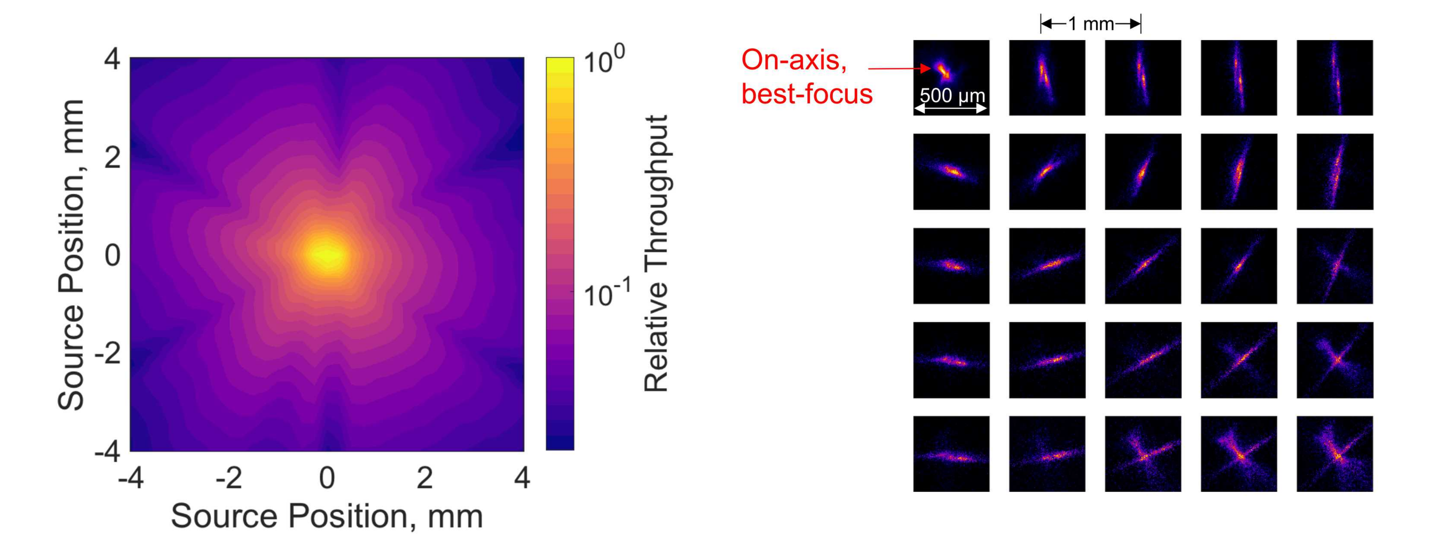
Mechanical design of the Wolter Imager on the Z Machine driven by:

- Long source-detector distance, 3.05 m
- Stringent alignment requirements of the optic
- Harsh Z environment

Related posters (High-Temperature Plasma Diagnostics 2018):
2.51 J. Vogel, 6.18 C. Ball, 14.38 B. Kozioziemski, and 14.53 M. Wu

The optic has been characterized extensively in the laboratory, aiding in future image processing

Throughput and point-spread function (PSF) vary significantly over FOV:



Left: Throughput map 2.5 mm away from best-focus. **Right:** PSF map of bottom-right quadrant of FOV
Bottom: PSFs on-axis at different focal depths

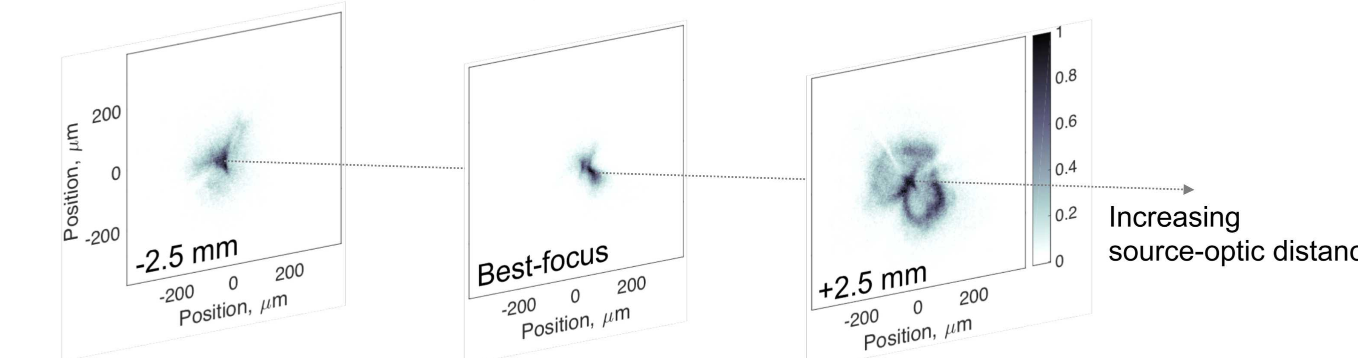


Image De-blurring

Wolter image, $g(r)$ of arbitrary source, $f(s)$ can be calculated with knowledge of PSF, $h(r,s)$:

$$g(r) = \int h(r,s) f(s) ds$$

Model shift-variant PSF as sum of shift-invariant PSF modes:[6]

$$h(r,s) = \sum_{p}^{N} a_p(s) c_p(r-s)$$

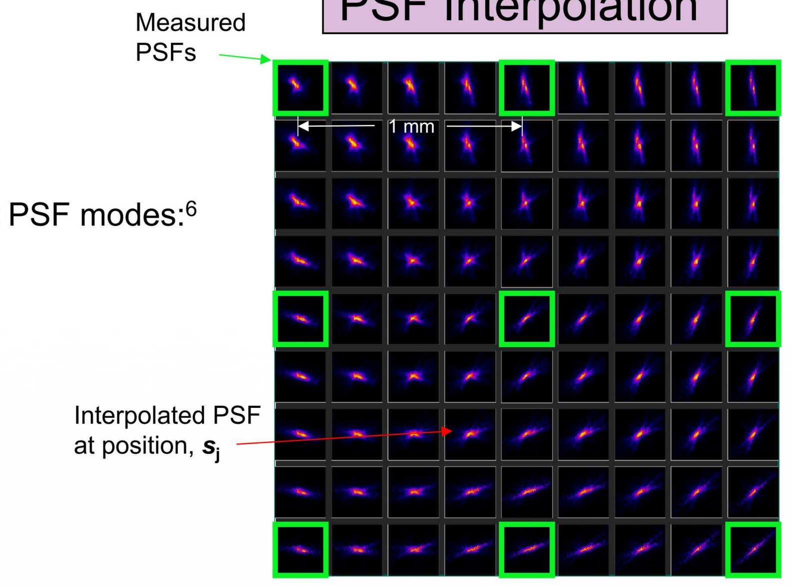
Shift-variant PSF; coefficients; pth shift-invariant PSF mode

Image is sum of convolutions of PSF modes with source weighted by coefficients:

$$g = \sum_p c_p * (a_p \cdot f)$$

Calculate source via optimization: $\hat{f} = \arg\min_f \| g_{\mathrm{data}} - g(f) \|^2$

PSF Interpolation



Conclusions

- Wolter imager has successfully imaged Mo wire arrays on the Z Machine in the 17-18 keV energy band
- Wolter has demonstrated a spatial resolution better than 150 microns and signal/noise ~12 over a greater than 5x5x5 mm³ FOV, significantly improving upon previous imaging capabilities
- Future image processing, in conjunction with calibration measurements will seek to de-blur images to discern sub-resolution structure in sources
- Future optic will be optimized to view 22 keV emission

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