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Progress on High Energy X-ray Imaging Tools at the US National Labs

We have fielded micron-resolution microscopes at 10.5 and 17.5keV, for imaging high-energy plasmas

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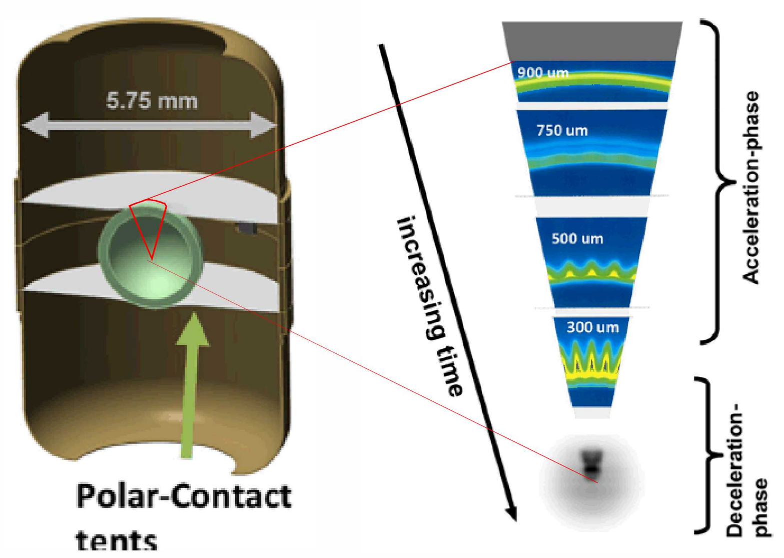
Abstract: *Since 2013, two multilayer-coated x-ray microscopes have been built and fielded at two US National Laboratories, with collaboration by NASA and university partners. Their purpose is to capture 9-17keV x-ray images of confined plasmas over very short times (< 1 ns) to study implosion dynamics. Imaging at high energies is necessary to see through surrounding lower-density plasma and capture behavior of the densest areas of the plasma. The Kirkpatrick-Baez Microscope at Lawrence Livermore National Laboratory (LLNL) images an area of ~ 300 μm x 300 μm with a resolution of ~6 μm, at x-ray energies of 8.8 to 11.8 keV. The mirrors are coated with Pt/C multilayers of dual d-spacing 44 and 65 Å. The microscope is used to study inertial-confinement fusion (ICF) experiments at the National Ignition Facility (NIF) at LLNL. The Wolter Imager2 at Sandia National Laboratories (SNL) images an area ~ 5 mm x 5 mm with a resolution of 60-300 μm in the on-axis region. Two mirrors intended for 17keV and 22keV are coated with W/Si multilayers of constant d ~ 34Å and 25Å. The imager is dedicated to studying Z-pinch plasmas at the Z-machine at Sandia National Laboratories (SNL).*

KB MICROSCOPE AT NATIONAL IGNITION FACILITY AT LLNL: (LASER-CONFINED PLASMA)

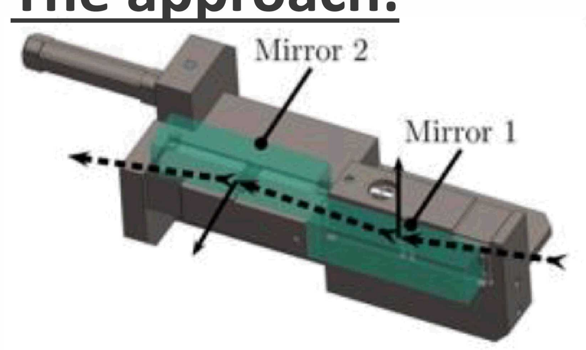
The challenge:

Image NIF plasma:

- 2mm He,H_2-filled target compressed by MJ laser pulse
- Plasma shock travels inward at at v ~ 10^5m/s
- Need to study growth of instability modes



The approach:



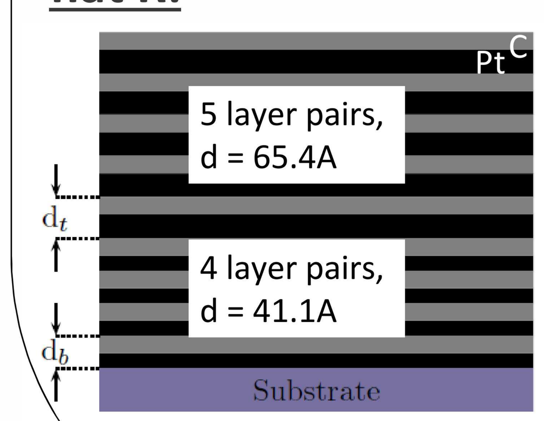
Kirkpatrick-Baez mirror chosen for:

- Lower technical risk fabricating and coating optics
- High spatial resolution

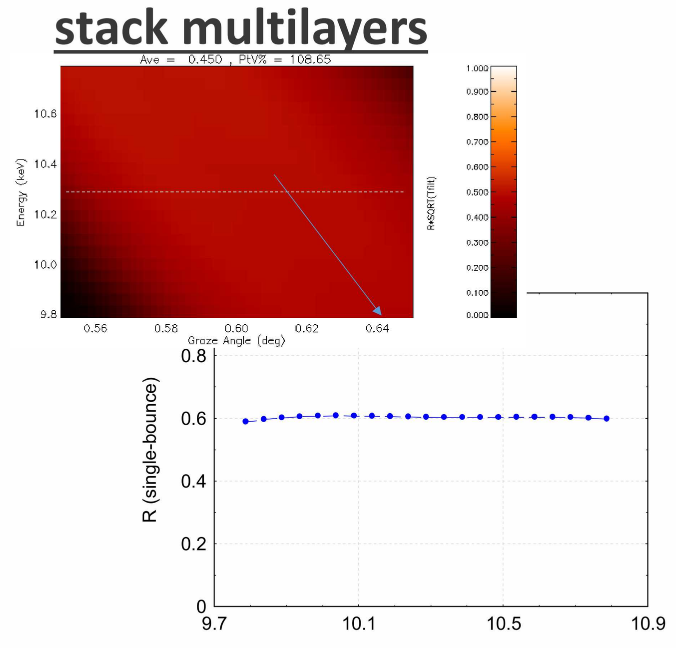
Multilayer Design Approach:

- Instrument priority is measuring feature brightness, so flat R(E) response is important
- This required flat R from θ = 0.55 to 0.65° and E = 9.75 to 10.75keV

dual-stack design for flat R:

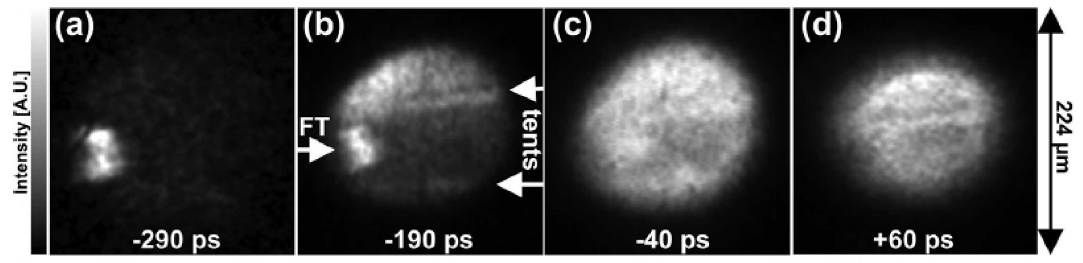


R(θ,E) & R(E) for dual-stack multilayers

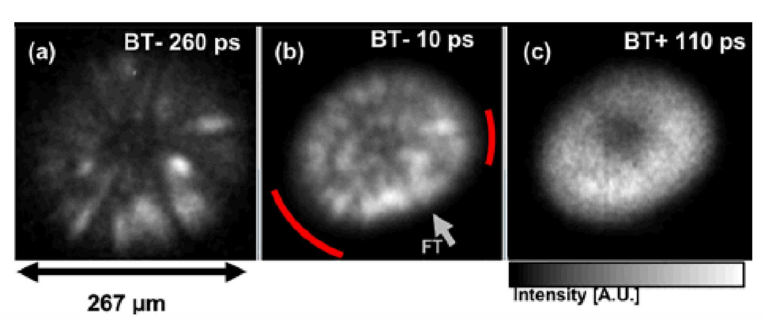


--- Image Results – 10.3keV: ---

KB microscope (resolution ~6um):



Competing pinhole camera, polar image of same experiment (resolution ~ 11um)

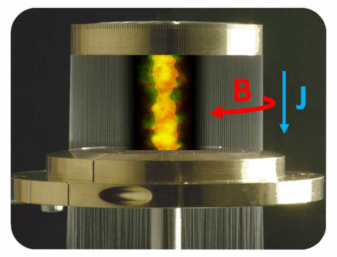


WOLTER MICROSCOPE AT Z-MACHINE AT SANDIA: (PULSED-POWER PLASMA)

The challenge:

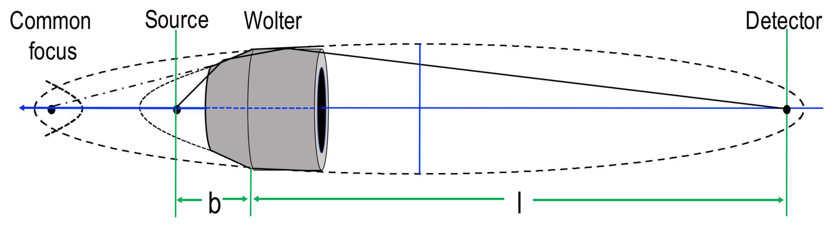
Image Z-machine plasma:

- Pulse power heats wire array
- Pinch implodes plasma at v ~ 10^5m/s
- Image plasma's x-ray emission (17 or 22keV) to study instabilities



The approach:

Wolter design has the large field (5×5×5mm) and large NA (10^{-4} st) needed to image cm-scale experiment



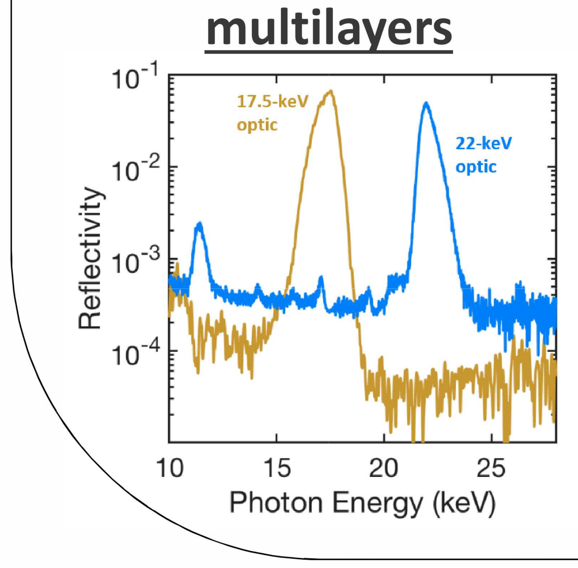
Fabrication:

1) Sputter W/Si double-stack ML on glass mandrel
2) Electroplate Ni support shell
3) Remove from mandrel

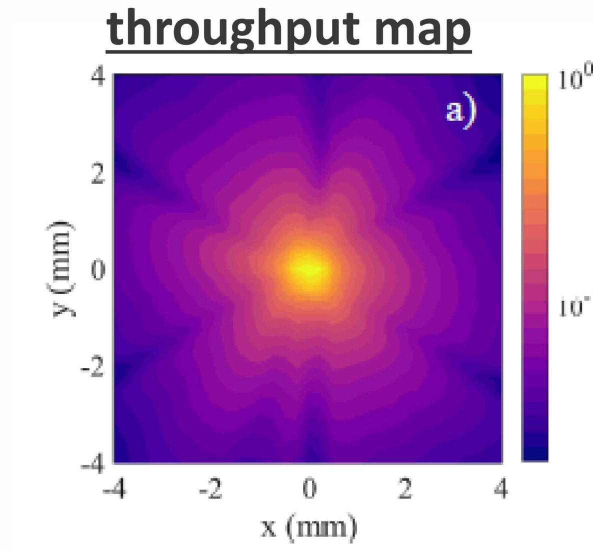
Multilayer Design Approach:

- Optic must reject substantial Bremsstrahlung background
- Wide FOV brings a large range of incidence angles
- After ray-trace testing, constant d of ~34.5A (for 17.5keV) and d ~ 25.4A (for 22.8keV) are optimal. W/Si chosen for proven stability
- Instrument priority is locating x-ray emitting regions, not flat response.

R(E) for constant-d multilayers

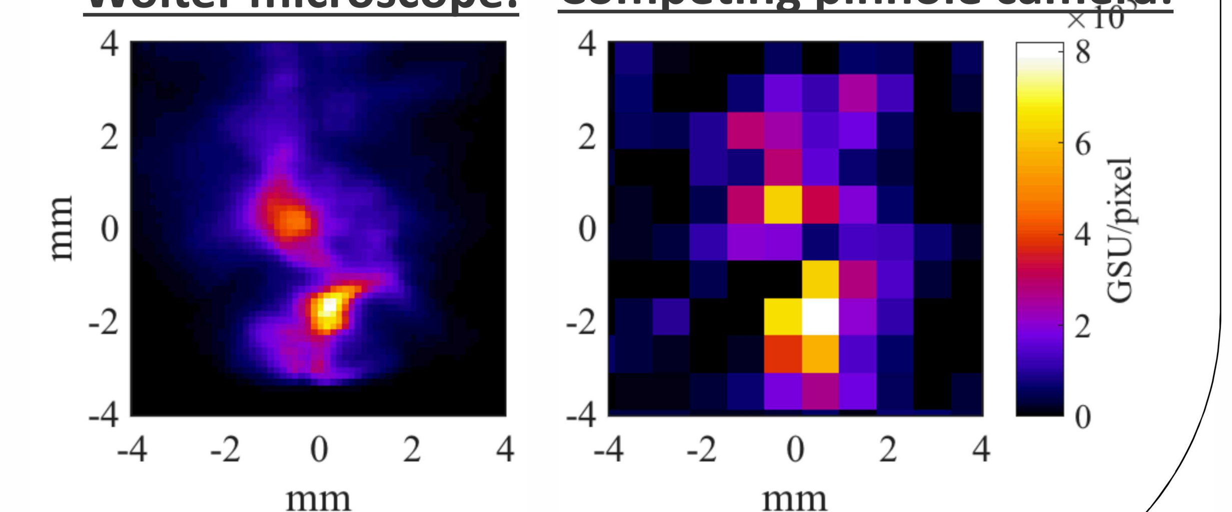


Resulting optic throughput map



--- Image Results – 17.5keV: ---

Wolter microscope: **Competing pinhole camera:**



Final resolution ~200um, limited by figure error of shells

FUTURE TOOLS: A NEXT-GENERATION WOLTER AT THE NATIONAL IGNITION FACILITY:

The challenge:

Image NIF plasma at higher energies:

- Imaging is needed at higher energies (20keV, then 50keV) is needed to diagnose full ignition shots (hotter than NIF experiments above)
- But for NIF it must also have high spatial resolution (5-10um), combining the best of the two instruments above.
- Interpretation is also a challenge: relating where the x-ray yield is to where the neutron yield is to understand a fusion process requires models, assumptions, and other diagnostics
- The NIF Wolter imager is planned at lower angle (θ = 0.3°) to accommodate lower available reflectance of best multilayers.

X-ray microscopes provide resolution and wavelength discrimination, and are reaching <10μm resolution.

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