X-ray Imaging 2 Outbrief

Lawrence Livermore National Laboratory

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X-ray Imaging 2 Outbrief

David Bradley

For

C. Bourdon, J. Vogel, J. Koch, P. Hakel

X Ray imaging 2 consisted of 4 presentations

- Vogel
  - X-ray imaging with Wolter optics in the 15-50 keV range
- Bourdon
  - Wolter Imaging On Z
- Koch
  - XDV: A proposal for an X-ray Doppler Velocimetry diagnostic
- Hakel
  - Development of FESTR:
    a new spectroscopic modeling and analysis code

[1] A. Kritcher et al, Phys. Plasmas **21**, 042708 (2014)

Peter gave a description of the FESTR code

- Summarized the LANL suite of atomic modeling codes
- **F**inite- **E**lement **S**pectral **T**ransfer of **R**adiation
- Descriptionof how code was structured and optimized
- Gave examples of calculating spectra from non uniform mixed plasmas
  - D/Ar sphere
  - Raytracing to produce synthetic images
- Examples, including published data and Omega DT/Ar experiments

[1] A. Kritcher et al, Phys. Plasmas **21**, 042708 (2014)

Julia outlined the current status of the NIF Wolter imaging concept

- Outlined the basic principles of Wolter optics and the use of multi-layer coatings to extend the energy range of reflective x-ray optics
- Discussed the parameters influencing optical design and multi-layer prescription
- Described NASA MSFC replicated optics process
  - Producing multiple optics from a single mandrel
- LLNL's program for high-E, small-d multilayers
  - Acts as a notch or pass-band filter for SNM lines from 90–400 keV
- Explained how development of Sandia Wolter will feed into NIF design
- Summarized current thinking on options for NIF system
  - trade-offs of interconnected multi-dimensional parameter space
- Schedule for NIF and Wolter systems

[1] A. Kritcher et al, Phys. Plasmas **21**, 042708 (2014)

Preliminary "desirements" for Wolter imaging on NIF

Desirement	Specification
Field of View	At least ± 150 μm
Spatial Resolution	Detector limited or 5μm FWHM
Efficiency	At least ×100 over standard pinhole
Depth of Field	~3mm
Total throw (under study)	2m, 8m, 22m
Magnification (depends on detector)	At least ×10

Before conducting a dedicated design effort for Wolter at NIF, we need to:

1. Conduct the broadest possible census of the NIF user community to understand their needs
2. Ingest lessons learned from X-ray imaging (using KB optics) at NIF
3. Ingest lessons learned from development and deployment of Wolters at Z

Schedule


Wolter Microscope
FY15
FY16
FY17
FY18
FY19
FY20
Tasks
O N D J F M A M J J A S
Z Tasks
NASA Contract Placement
CDR
Wolter Manufacturing
Development of Calibration Capabilities
Optic Testing
Design of Optic Alignment Assembly
Design of Detector (Time-integrated)
IDR
Final Design of Mechanical Components
FDR
Manufacturing
Commissioning
Integration of H-CMOS detector
NIF Tasks
NIF Nested T_e
Point designs for potential experiemnts
Wolter optic design and test
Systen Design and Engineering
NIF Strength (50 keV)

Chris outlined status of Z Wolter project

- Need for 15 keV imaging systems
  - Requirements for monochromatic Ka imager
- Why a Wolter is being considered
  - Large FOV, custom tailoring of spectral bands, high throughput
  - Increased standoff distance for similar resolution & signal vs PH
- Showed proposed location for mag = 3 Wolter microscope on Z target chamber with optic ~75 cm from the source
- Parametric design space for SNL Wolter Optic
- Resolution vs spot size
  - Can meet requirements
    - Calculations do not include figure error or roughness yet
- Alignment plans
- Detectors
  - Image plate at first, gated CMOS for future
- Schedule for Z and NIF

[1] A. Kritcher et al, Phys. Plasmas **21**, 042708 (2014)

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
- $\eta \approx 10^{-5}$

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
- $\eta \approx 10^{-5}$

Case C1 (Mo)

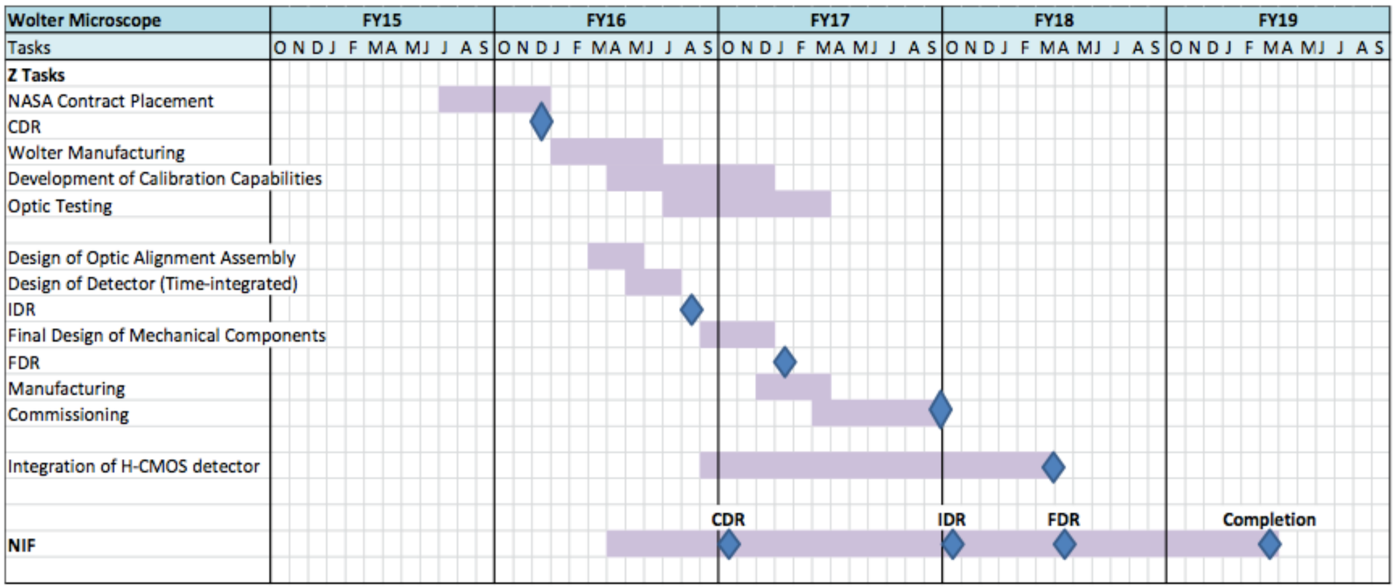
- M=4
- D= 3.00 m
- Mirror length (L_H)= 20 mm
- θ_i = 0.47°

(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

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

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- Collaboration is working, but effort is still in initial concept phase
- Needs to move to a firm design soon

One possible area needing attention is in calibrations

- Calibration facility currently does not exist
- Where (LLNL?) and when is facility needed and when should we begin setting it up ?

National Laboratories

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 (~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°) and two-axis translations (~ 1μm)
- Hard x-ray imaging detectors: CCD-based hard x-ray imager

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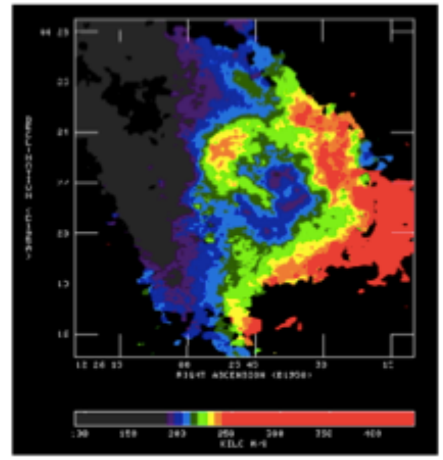
Jeff proposed multi-spectral x-ray imaging (sensitive to Doppler wavelength shifts) to map line-of-sight velocities in laboratory plasmas

- Multi-spectral imaging (sensitive to Doppler frequency shifts) is used to map line-of-sight velocities in astronomy
- Multiple monochromatic imaging with bent crystals can provide multi-spectral x-ray images
  - Can arrange several crystals, tuned to different center wavelengths within the profile of an emission line, to produce a multi- spectral image mapping wavelength shift to line-of-sight velocity
- Simulations of data from a simple rotating plasma ball at 5 different wavelengths show striking differences from broadband images
- Extension to using a 3D HYDRA of non-uniform implosion
  - simulation with

Motion in an object can be mapped using multi-spectral imaging of Doppler shifts

NGC 4449, white light visible map



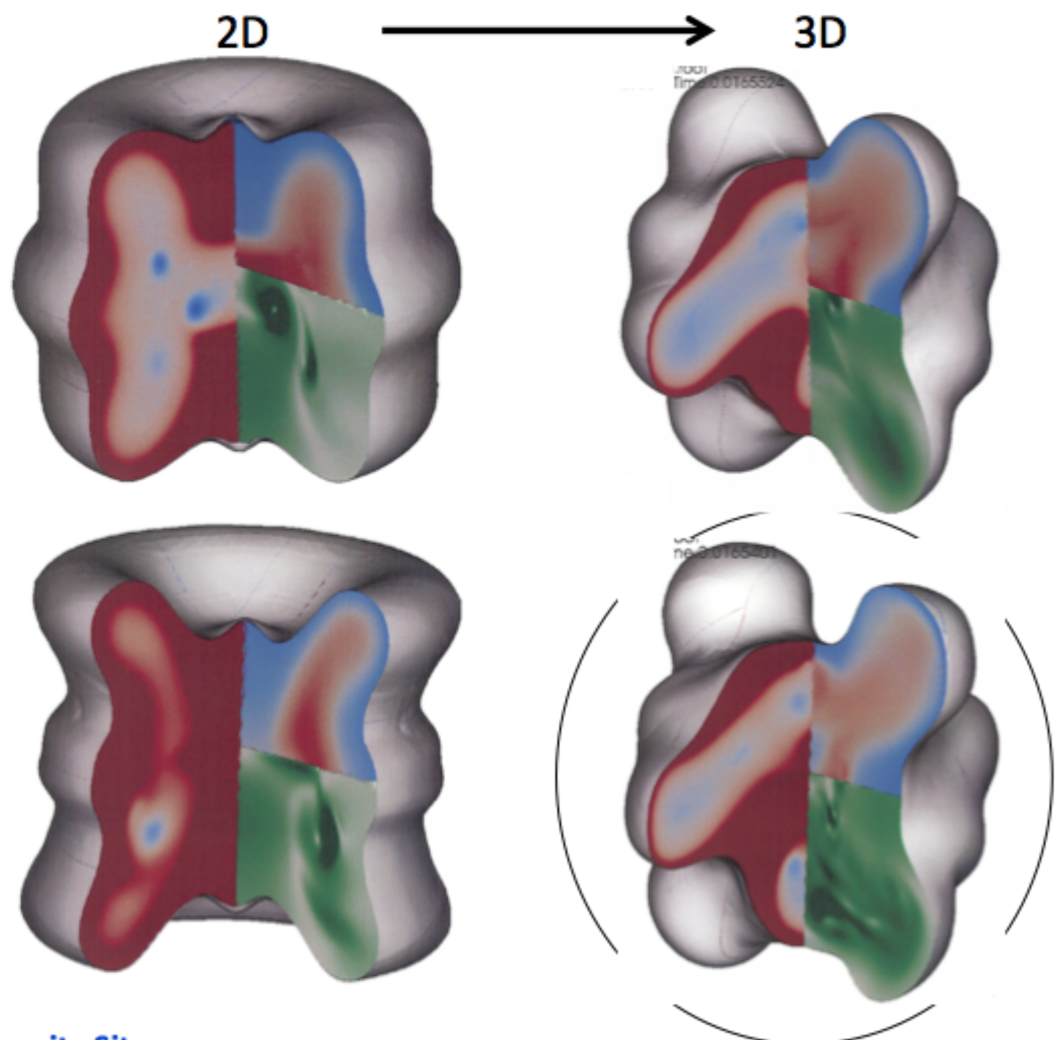
NGC 4449, multispectral microwave map

- **Multi-spectral imaging (sensitive to Doppler *frequency* shifts) is used to map line-of-sight velocities in astronomy**
  - **Galaxy NGC 4449 is irregular in white light optical images**
  - **It is revealed to be rotating as a whole, with counter-rotating portions indicating an ancient galaxy merger, in multi-spectral microwave (21 cm) images**

We can use multi-spectral x-ray imaging (sensitive to Doppler *wavelength* shifts) to map line-of-sight velocities in laboratory plasmas

We have begun to explore realistic 3D Hydra simulations of NIF implosion plasmas

More realistic 3D perturbations amplify weak spots[5]



CR ~ 30
Standard capsule fill

Increased CR worsens asymmetry

CR ~ 33
Reduced fill 0.33x

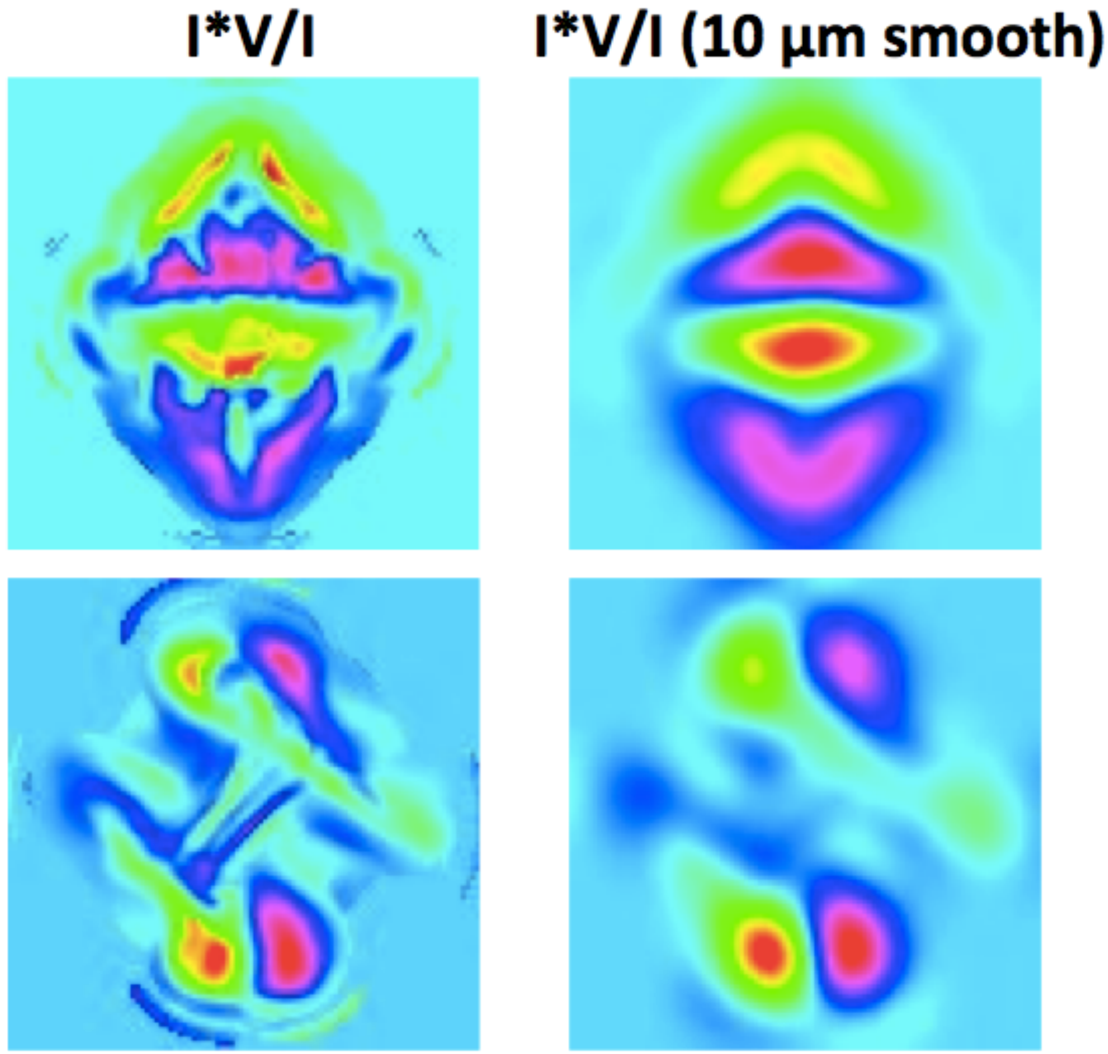
Weak spots relieve pressure

Weak spots are more exaggerated at high CR

[5]Slide from B. Spears, LLNL
Post-shot of N130927

2D maps of weighted line-averaged velocity shows significant variations

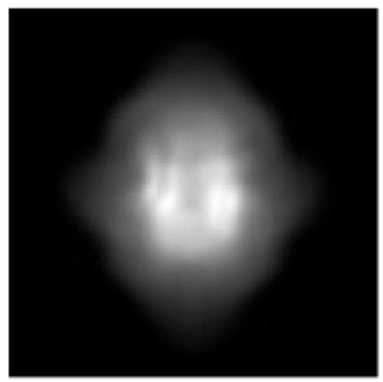
- Weighted velocities exceed +/- 200 km/s even with line of sight averaging
- Blurring the maps by 10 µm still shows obvious structure, +/- 100-150 km/s maximum velocities
- Indicates spatial resolution of 5-20 µm is adequate to observe
  - Time resolution requirements TBD



Preliminary polar XDV monochromatic images from 3D implosion are strikingly different

λ_1 λ_2 λ_3 λ_4 λ_5

Monochromatic images (polar view) at the same five wavelengths



Broadband image (pinhole, KB, Wolter) of the same object is insensitive to velocities

Diagnostic potential is huge:
Survives analysis of 3D implosion with line-of-sight averaging

Conclusions

- Multiple narrow-band crystal imagers, tuned to different wavelengths within the motional-Doppler-broadened profile of a suitable emission line, can be used to measure the distribution of bulk velocities in a NIF implosion plasma
  - Direct diagnostic of how much implosion energy is partitioned into non-thermal motional energy
  - Potentially critical diagnostic for ignition on the NIF
  - Analysis of a simple rotating-ball plasma is promising
  - Preliminary analysis of 3D implosion simulations from Hydra (high-CR post-shot of N130927) is promising
  - Photometrics are promising
- Extensions to other HEDP plasmas (Z, DPF, UNR-Zebra) seem straightforward, possibly easier than NIF applications (cooler temperatures, larger spatial scales); we will explore a 2-crystal prototype for UNR-Zebra first
- Extensions to cold plasmas (e.g. explosive-driven implosions at NNSS) are possible in backlit absorption geometries
- Exploration of these applications in more detail is supported by NSTec SDRD program (LO-004-2016)

The proposed XDV system looks very promising and could have very high potential

- More simulations with realistic detector responses…
- Simple 2 crystal prototype should give interesting data set
- Are there other facilities that might also be a good place to test the concept?
  - Magpie (rotating plasma)
  - Z?
  - ?