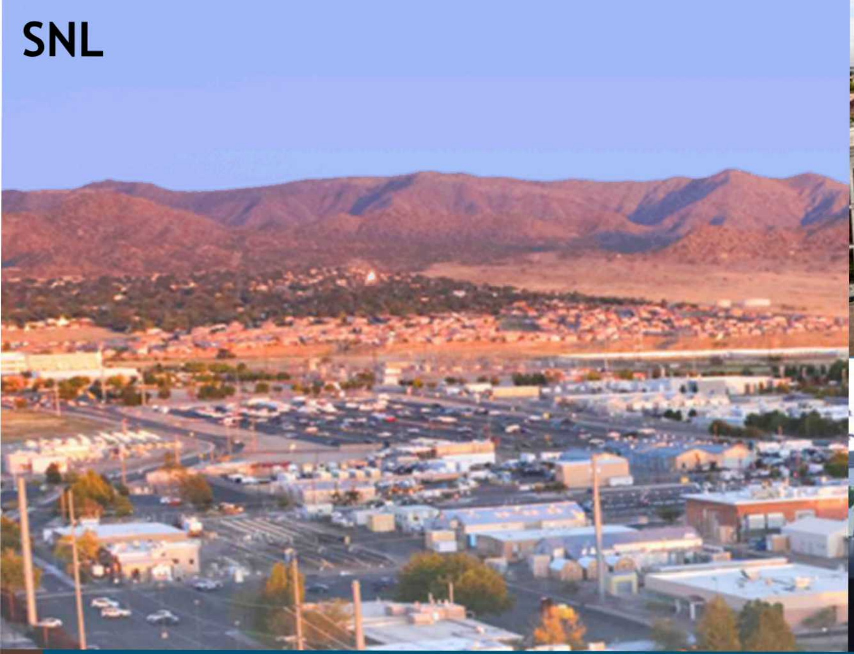

SAND2019-14886PE

Developments in X-ray Crystal Imaging and Spectroscopy at LLNL, SNL, and LLE.

Eric Harding (Sandia National Laboratories)

December 10, 2019

Meeting of the National Diagnostic Working Group (Livermore, CA)

Sandia National Laboratories is a multi-mission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

This presentation showcases the work from many folks:

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Lawrence Livermore National Lab, Livermore, CA

Christine Krauland

General Atomics, La Jolla, CA

Marius Schollmeier, Grafton Robertson, Paul Gard, Greg Dunham

Sandia National Lab, Albuquerque, NM

L. Gao, K. W. Hill, M. Bitter, B. F. Kraus, and P. Efthimion

Princeton Plasma Physics Laboratory, Princeton, NJ, USA

Christian Stoeckl

Laboratory for Laser Energetics, Rochester, NY

Yefim Aglitskiy

Naval Research Laboratory, Washington, DC

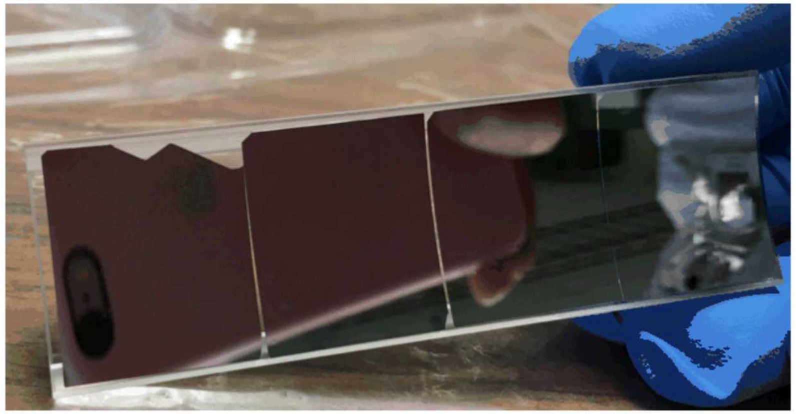
Across the labs new crystal spectrometers and imagers are being developed :

- **LLNL**
  - HiRAXS : EXAFS spectrometer
  - tConSpec: Streaked continuum spectrometer
  - CBI at 7eV+ cavity backlighters
  - CBI for self-emission imaging of Ge florescence
- **SNL**
  - MONSSTR: Dual spherical crystal, time-gated spectrometer with hCMOS
  - CHEWI3 : Triple-crystal, self-emission imager
  - SCDI : Diffraction using an x-ray relay mirror
- **LLE**
  - Investigating the limits of an aspherical x-ray optic

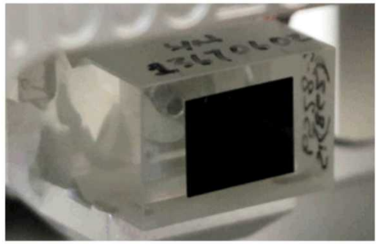
High-quality, bent crystals are at the heart of many of our x-ray imaging and spectroscopic diagnostics.

XRS3 -Spherically-bent Ge (Sandia)

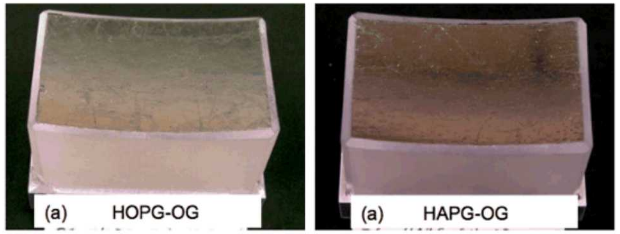
DHIRES – tiled Ge crystal, cylindrical shape (LLNL, PPPL)



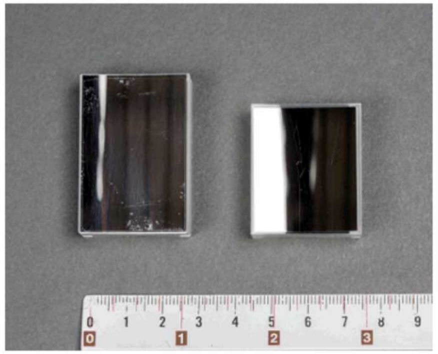
CBI-spherical (LLNL)



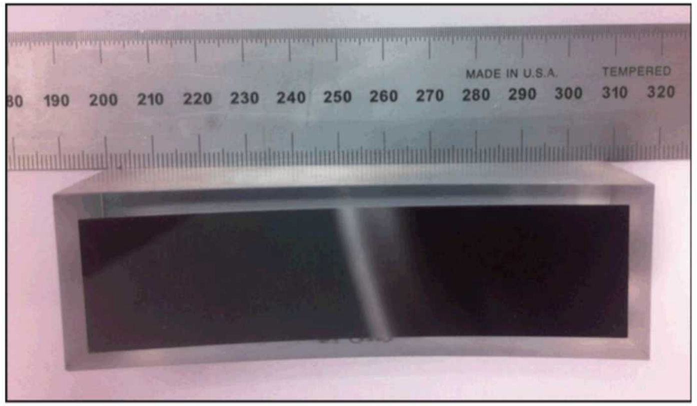
XRS3 -Spherically-bent graphite (Sandia)



DHIRES – Ge, Conical (LLNL, PPPL)



HiResSpec – Si crystal(LLE)



25 x 100 (!) mm
R = 330 mm

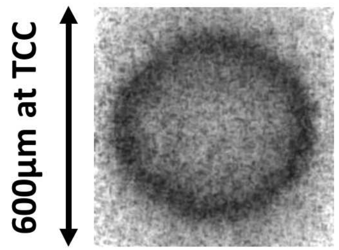
Transmissive type optics not shown.

The NIF crystal backlighter imager (CBI) demonstrated operation at 7 keV (w/cavity backlighters) and in a self-emission mode.

Increased image contrast at 7 keV.

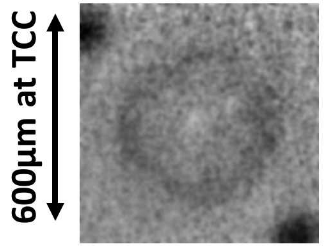
7 keV (N190902)

R_capsule = 211µm



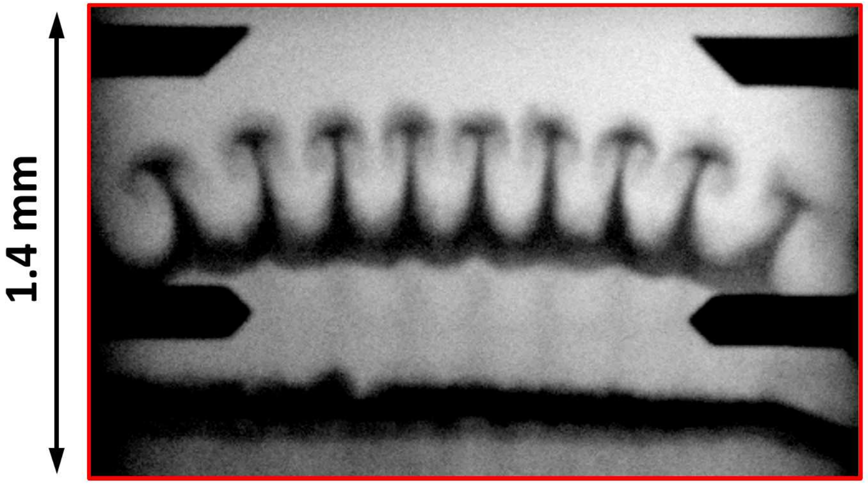
11.6 keV (N180520)

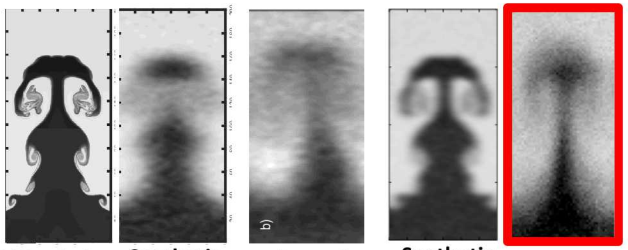
R_capsule = 169µm



Highly resolved RT spikes at 7 keV

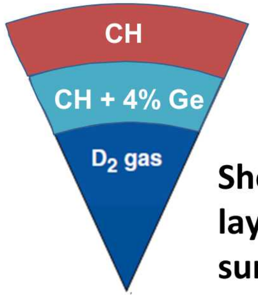
Estimate 8.5 µm resolution over entire image



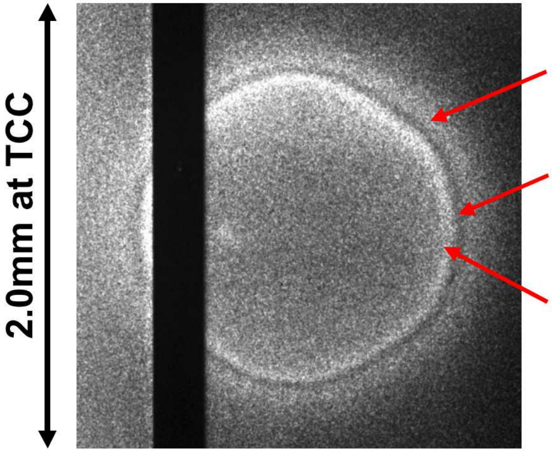


ARES Simulation J. Bender | Synthetic Radiograph with 21 um resolution | Example data from NIF shot with 22 um resolution | Synthetic Radiograph with 9 um resolution | CBI data from N190213-002

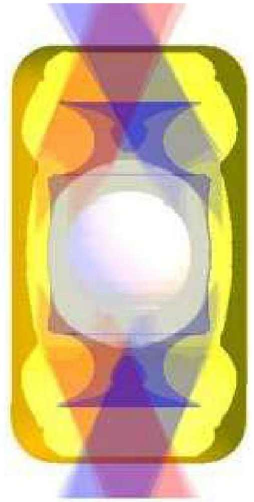
Self-emission imaging of Ge florescence

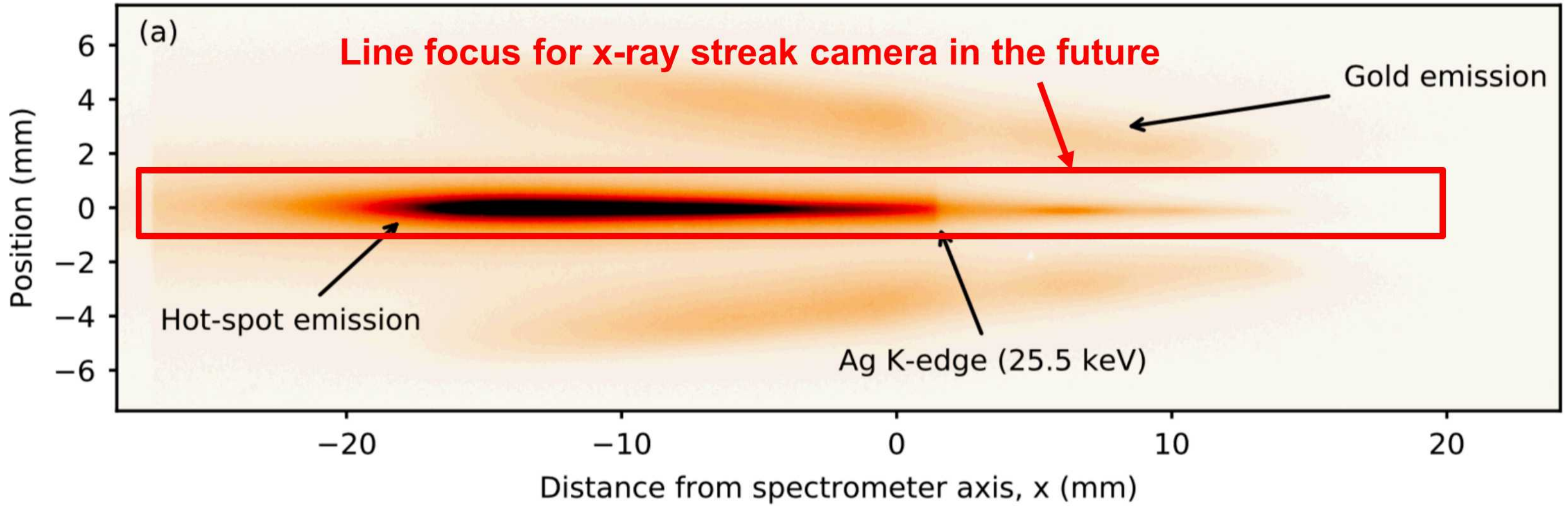


Shot 1: Ge doped layer on inner surface



$T_e(t)$ measurements can be achieved by coupling ConSpec[1] to a streak camera.



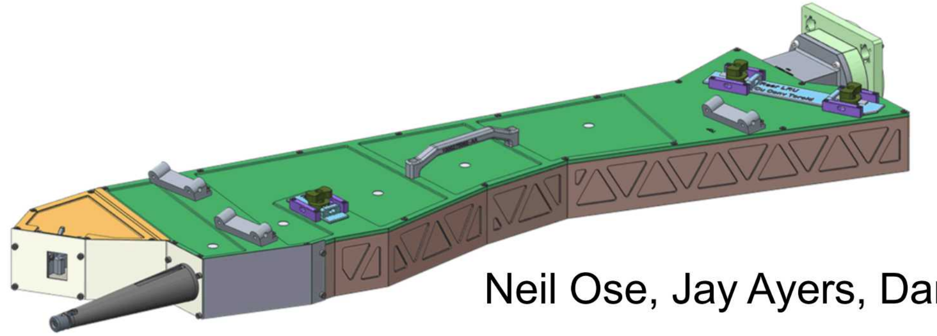


ConSpec:
Absolutely calibrated continuum emission.[2]
T_e = 3.65 keV
[3.42 -3.98 keV]
N180109-001

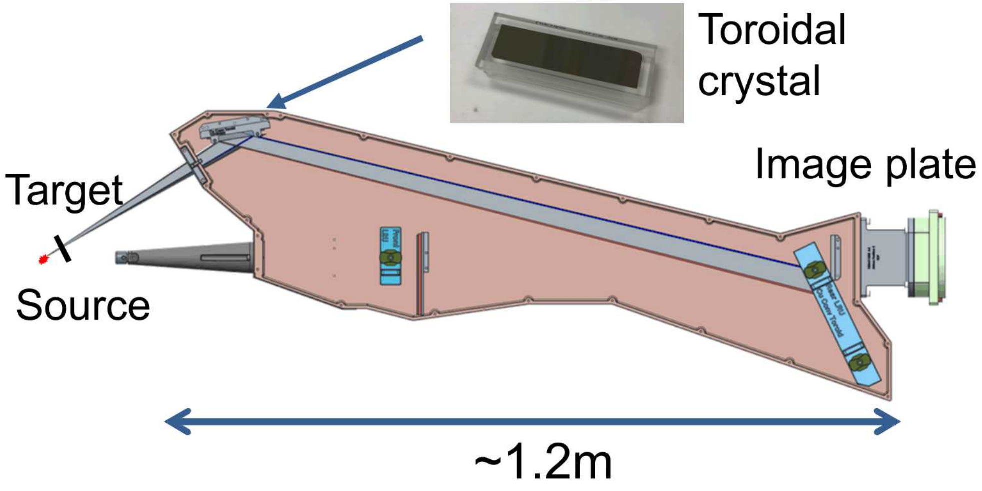
tConSpec: modifications need to work with DISC:
(1) Increase HAPG thickness to increase reflectivity (4x).
(2) Change target-to-crystal to 75 cm (was 90 cm) to fit data on 24 mm long photocathode.
(3) New snout design
(4) Put IP in front of photocathode for time integrated measurements.

[1]*D.B. Thorn et. al. SPIE (2017),* [2]*M.J. MacDonald et. al. JINST (2019)*

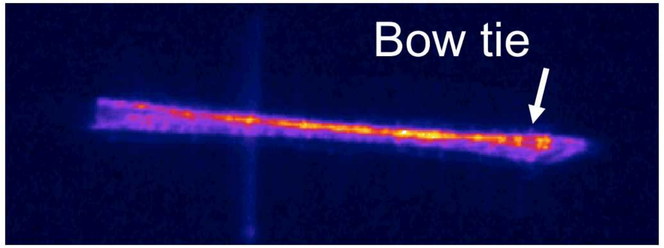
The NIF EXAFS spectrometer (HiRAXS*) will require toroidal and modified toroidal shapes to achieve high-sensitivity with high E/ΔE.[1]



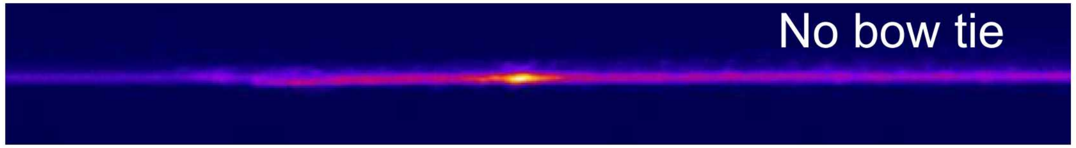
Neil Ose, Jay Ayers, Dan Thorn



- **Initial measurements with Cu targets and then advancing to higher Z-elements Ta and Pb.**
- **Lower signals on higher Z-elements require large aperture crystals and hence complex shapes to reduce aberrations.**



Optical focusing of conventional **toroid**



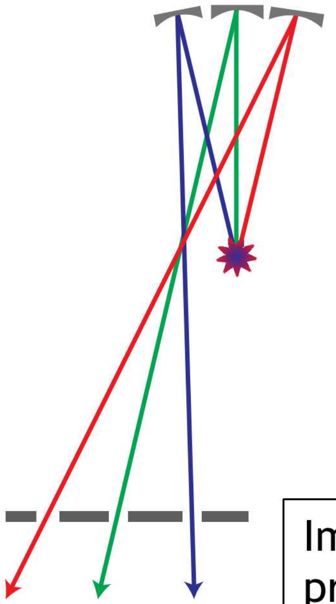
Modified toroid

*High Resolution Absorption X-ray Spectrometer

[1]Collaboration with PPPL: Lan Gao, Ken Hill, Manfred Bitter, Phil Efthimion

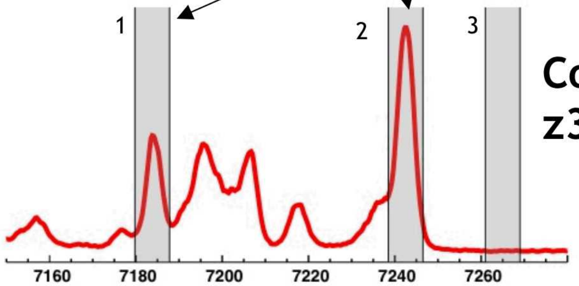
A triple crystal imager (CHEWI3) is being developed to measure $T_e(r)$ and $n_e(r)$.

Conceptual Operation:



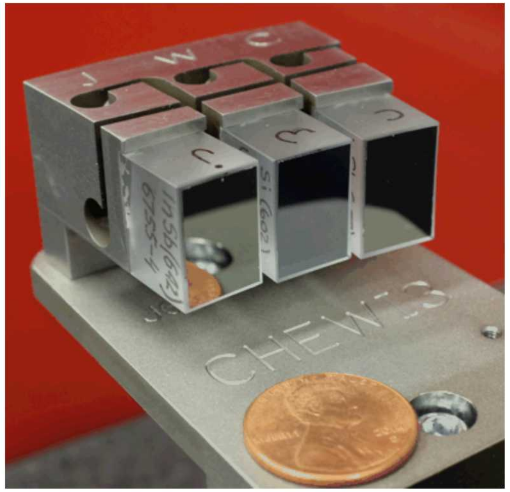
Collect three narrow band (8 eV) images tuned to spectral lines.

Image ratios provide T_e or n_e

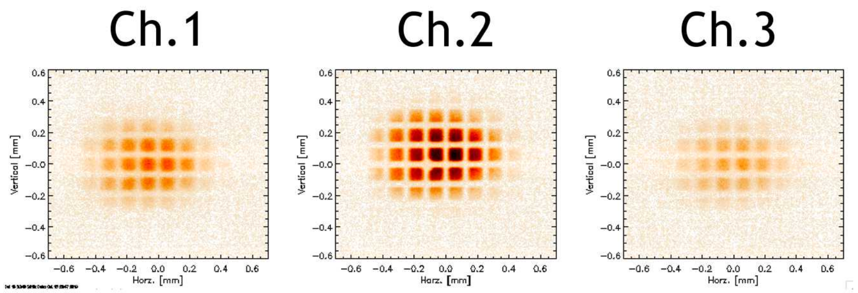


Co K-shell z3078

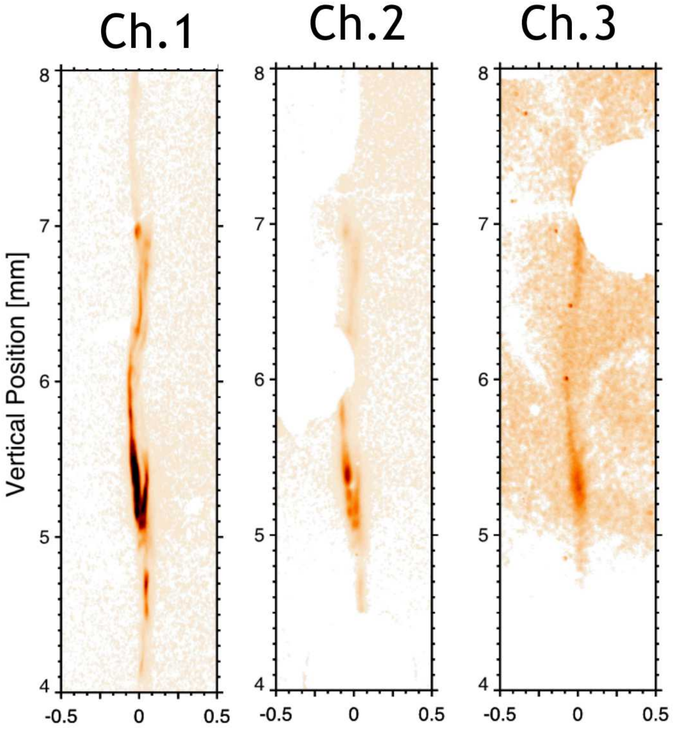
Assembly and Testing:



Backlit grid images from offline testing confirm good focusing.



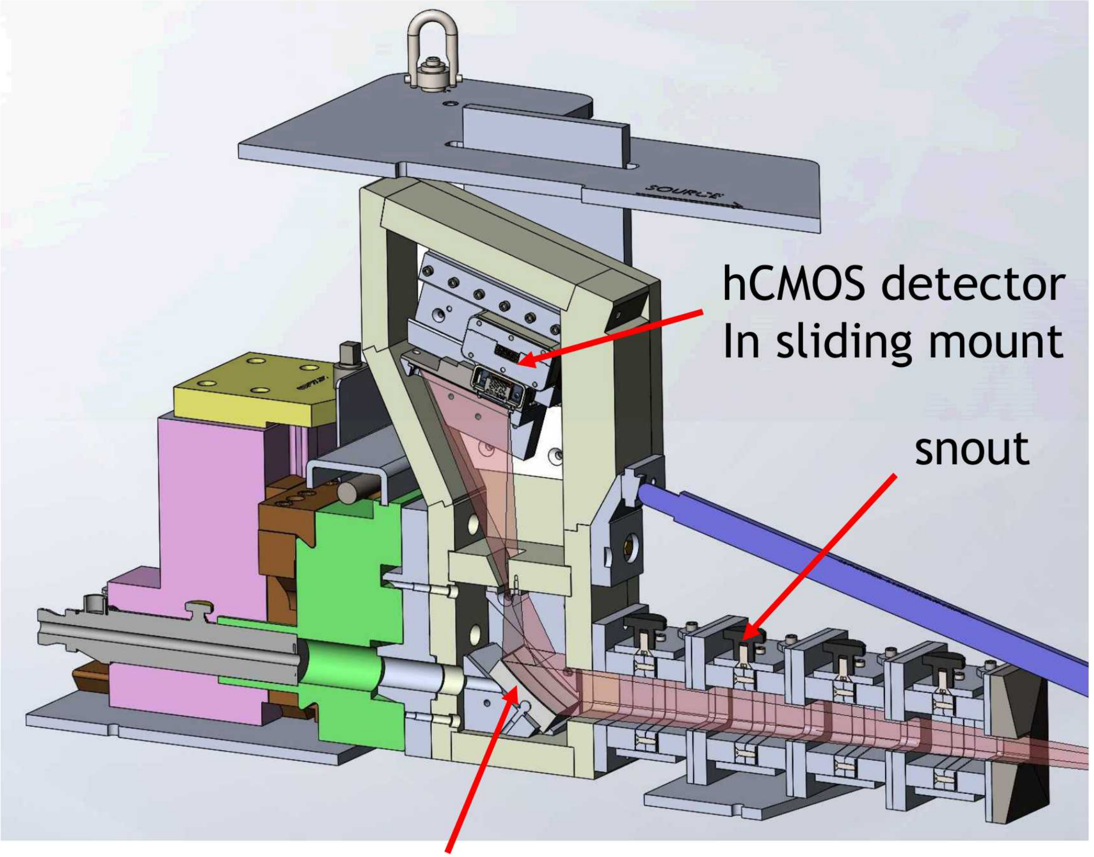
Z-shot (z3421) Oct. 24, 2019:



2nd shot will improve data quality by using more debris shielding.

A new, high-spectral resolution, time-resolved spectrometer (MONSSTR*) is being to developed to support MagLIF mix measurements.

In-chamber Spectrometer: MONSSTR



Spherical crystal (Quartz 20-23)

MONSSTR Parameters

Detector	Icarus	Daedalus (tiled)
Δt	2 ns	1 ns
Δx	0.2 mm	0.2 mm
Max. Frames	8	12
E/ΔE	~2000	~2000
Spectral Range[1]	6290-6800 eV	6290-7275 eV
Throughput	2e-7 str	2e-7 str
Spectral lines	Fe Kα to Fe He-α	Fe Kα to Co He-α

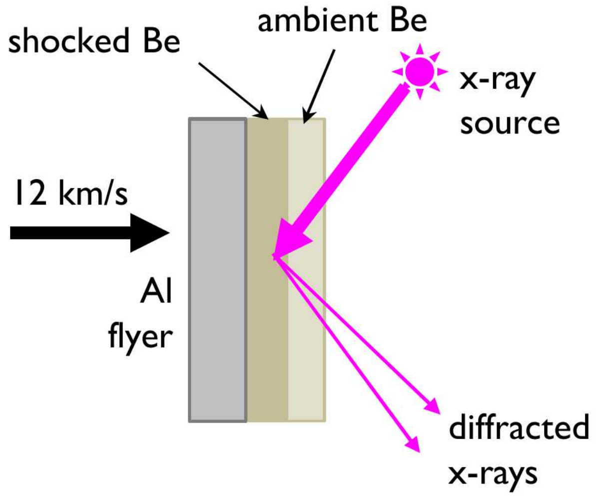
[1]Spectral range can be modified by moving detector and changing crystal 2d-spacing.

*Multi-Optic Novel Spherical-crystal Spectrometer with Time Resolution

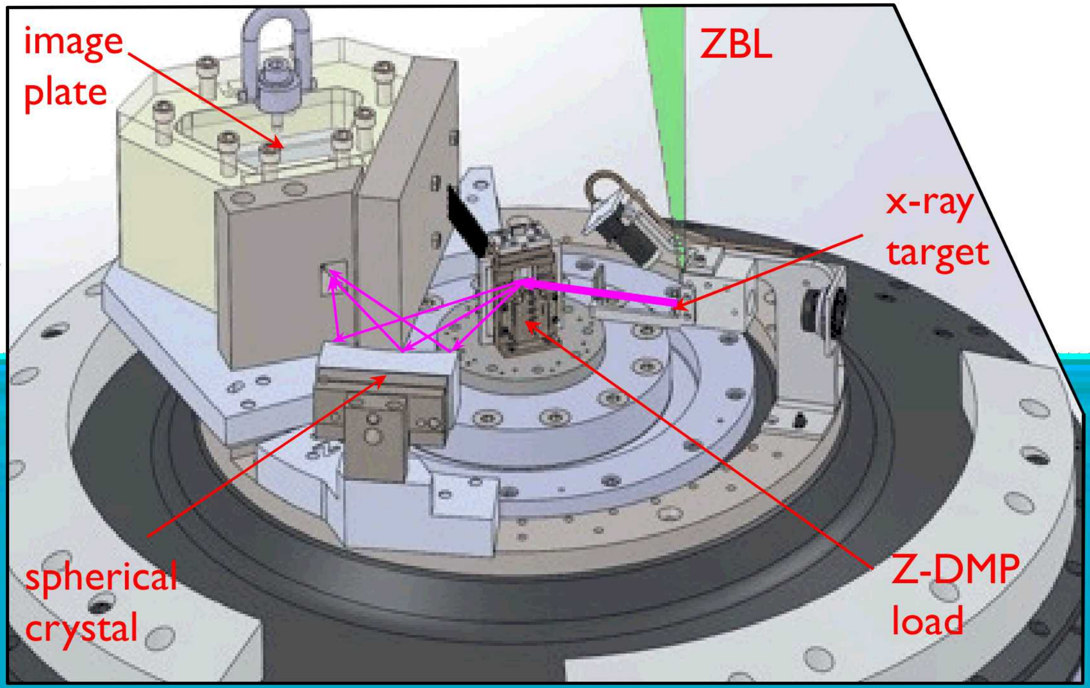
The SNL diffraction experiment use a spherical HOPG crystal to relay the diffraction signal into a tungsten box that protects the image plate.

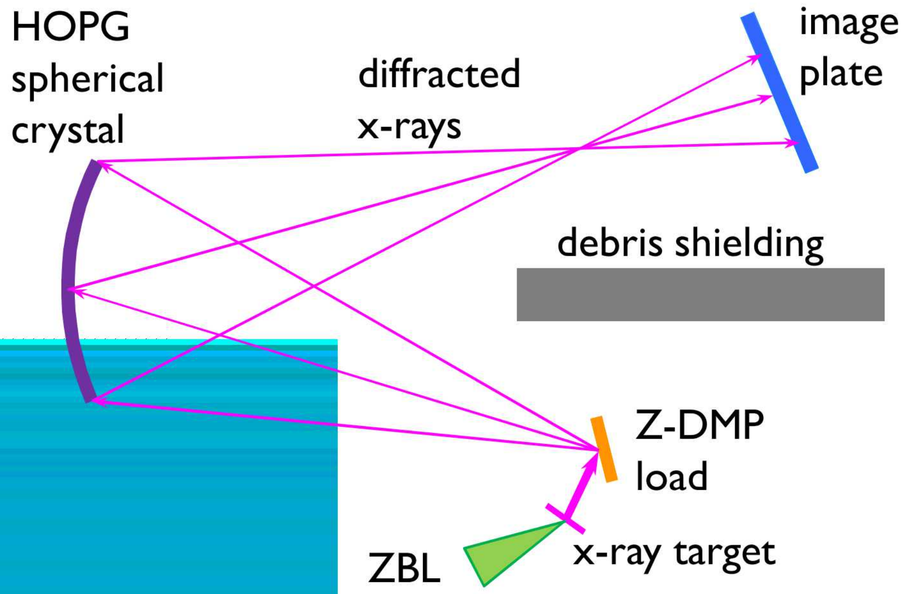
Experimental parameters

- Z-Beamlet laser ⟶ 6-8 keV x-rays
- HOPG spherical crystal ⟶ collect and reflect diffracted x-rays
- Image plate ⟶ record data
- Be sample ⟶ low mass attenuation coefficient, high XRD cross section
  - Serves as its own x-ray window
  - Possible hcp-bcc phase transition at ~2 Mbar, 3000 K*



Spherical Crystal Diffraction Imager (SCDI)



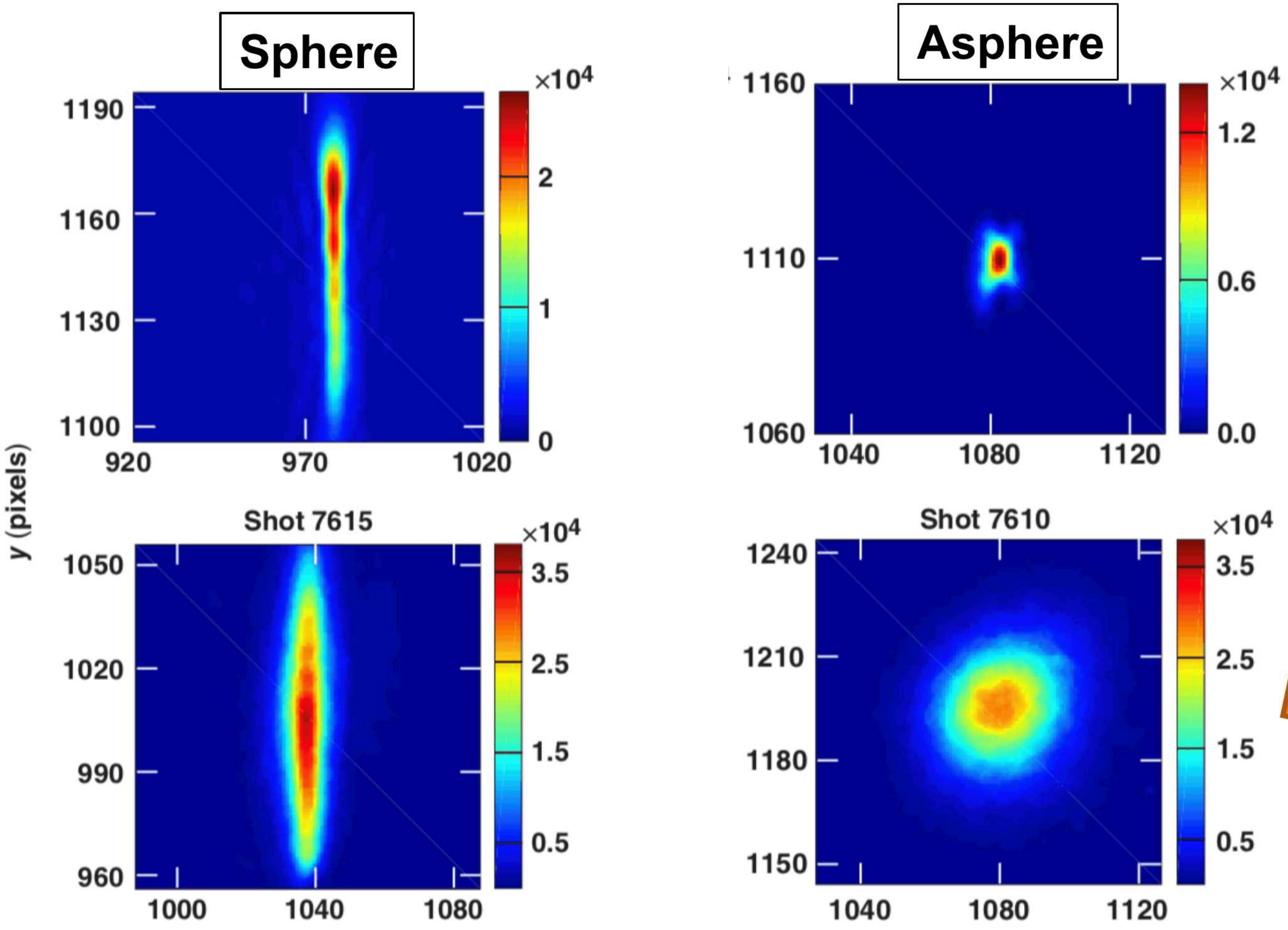


*A. Lazicki, *et al.*, PRB **86**, 174118 (2012)

LLE has developed a high-resolution crystal backlighter that relies on an aspherically shaped crystal.[1] However, aspheres are under performing.

Optical images of fiber tip

X-ray images of laser spot



Near diffraction limited **visible** image (~10 µm FWHM)

Large **x-ray** spot indicates poor focusing for the asphere.
22 and 43 µm FWHM
Theoretical: < 5 µm

Nino Pereira is looking into surface roughness effects.

[1]Stoeckl et. al., RSI (2014)

Key Questions for Crystal Imaging and Spectroscopy:

1. **What limits the ultimate spatial resolution?**
   A. Ray-tracing indicates a spatial resolution **<5 μm**. Can this be achieved? If not, why?
   B. Possible paths forward:
      1. Investigate surface roughness effects (Si vs. Quartz). Initial work by N. Pereira.
      2. Investigate shape errors with x-ray ray tracing.
      3. Design a high magnification (M>10x) asphere from Si and measure spatial resolution. This should be application driven.

2. **How do we build and characterize complex crystal shapes?**
   A. We need rocking curves, point spread function (PSF) measurements, and flat-field x-ray measurements.

3. **Are the current ray tracing capabilities adequate?**
   A. No, standard optical software does not use Bragg reflection.
   B. SHADOW and XRT are capable but too slow.
   C. M. Schollmeier is rewriting SXRT to incorporate advanced capabilities w/GPU.

Backups

Imaging and spectroscopy on Nike

Add Yefim's slide