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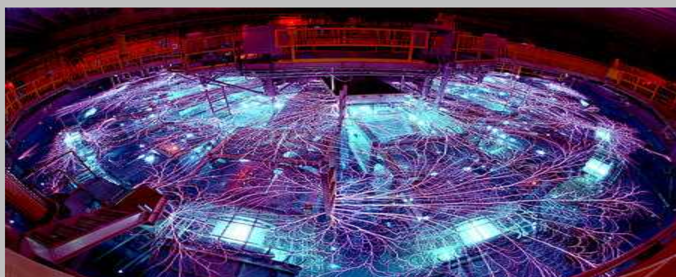

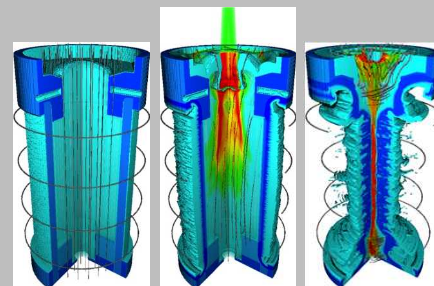

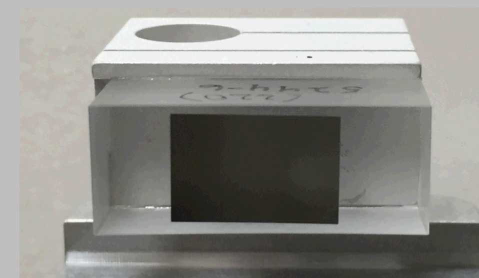

X-ray Imaging and Spectroscopy of MagLIF Experiments Using Spherically-Bent Crystals

E.C. Harding, M.R. Gomez, P.F. Knapp, S.B. Hansen, C.A. Jennings, S.A. Slutz, A.B. Sefkow, T.J. Awe, K.J. Peterson, K.D. Hahn, R.D. McBride, G.A. Rochau, and D.B. Sinars

Sandia National Labs, Albuquerque, NM

I. Golovkin

Prism Computational Sciences, Inc., Madison WI

Z Beamlet

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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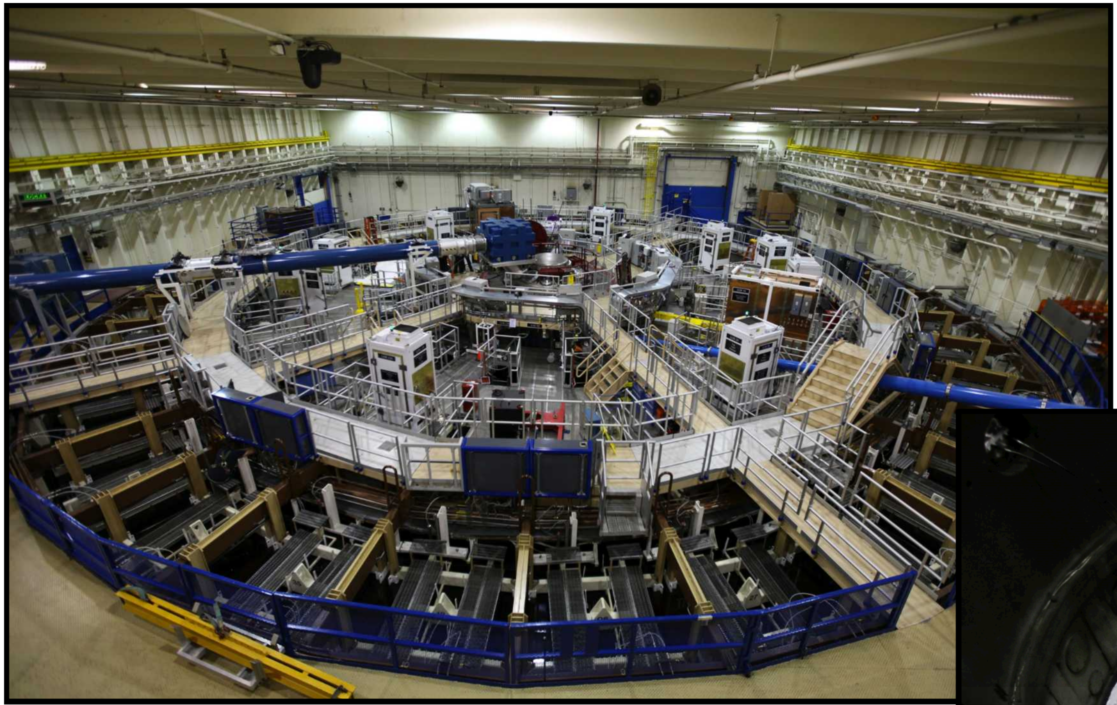
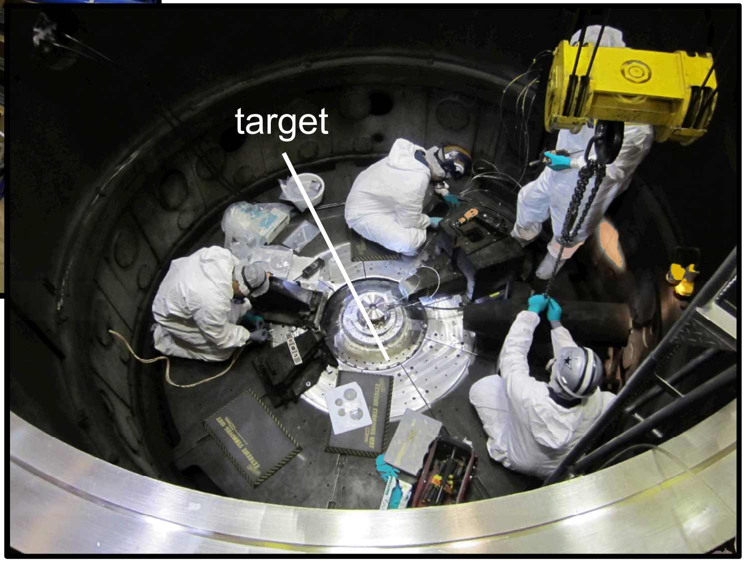
The Z machine is an impressive MJ class, pulse-power driver that is being used to study a megneto-ICF concept known as Magnetized Liner Interial Fusion (MagLIF)[1].

Z Machine Panorama



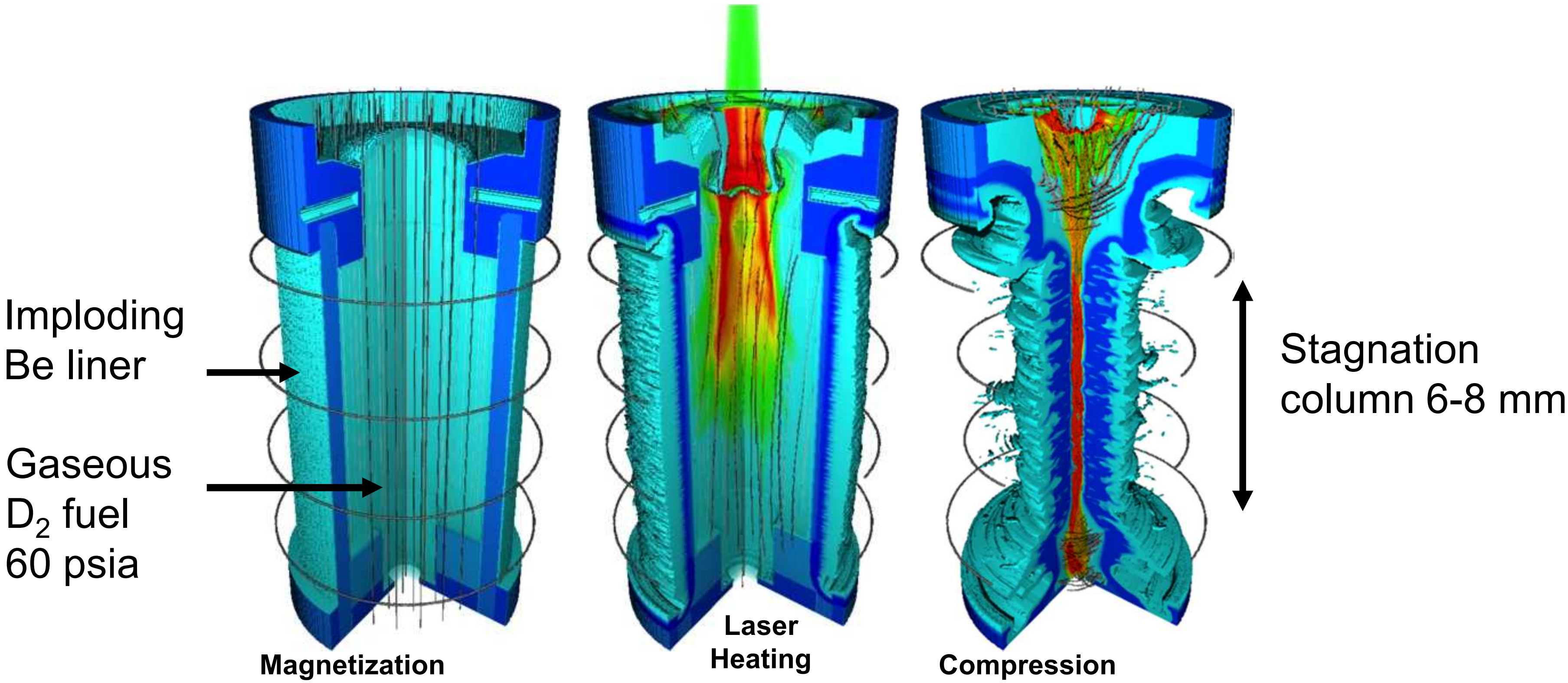
Machine Center



22 MJ peak stored energy
~1 MJ to target
26 MA peak current
100–300 ns pulse lengths

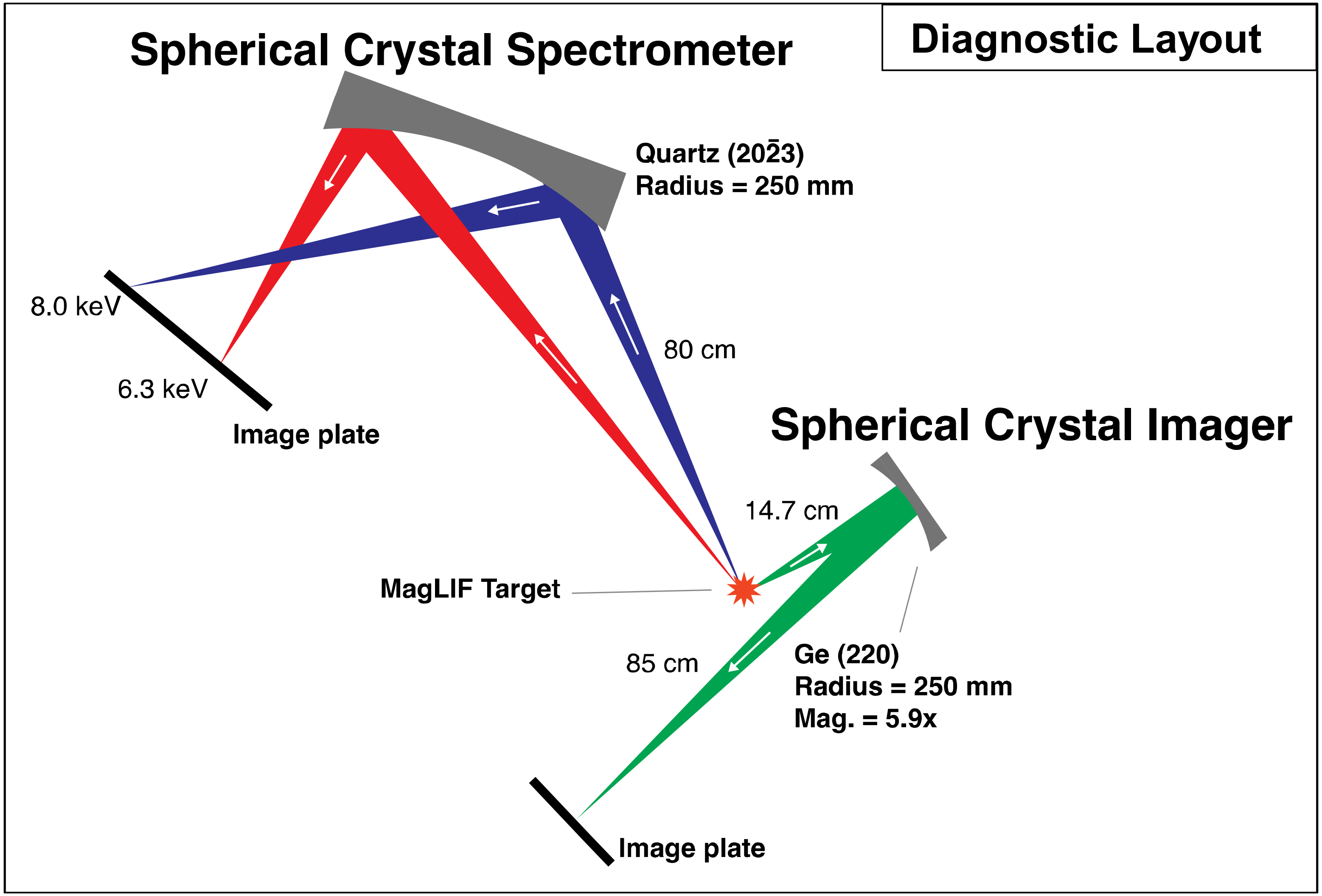
[1]S.A. Slutz *et. al.*, PoP 2010

The Magnetized Liner Inertial Fusion (MagLIF) platform[1] has motivated the development of high-sensitivity, x-ray diagnostics for measurements of morphology, T_e, and n_e of the stagnation plasma.

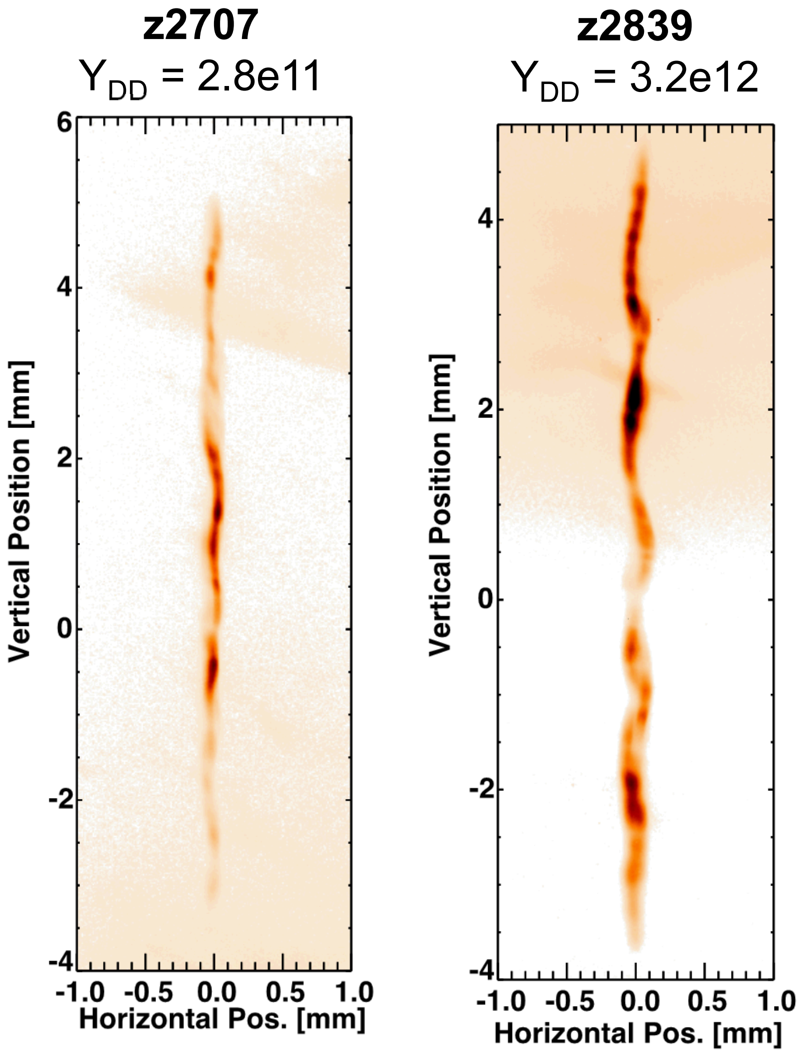


[1]M.R. Gomez et. al., Phys. Rev. Letters (2014)
Graphic by C.A. Jennings

High-sensitivity x-ray imaging and spectroscopy is made possible through the use of spherical crystals that collect and focus incident x-rays.



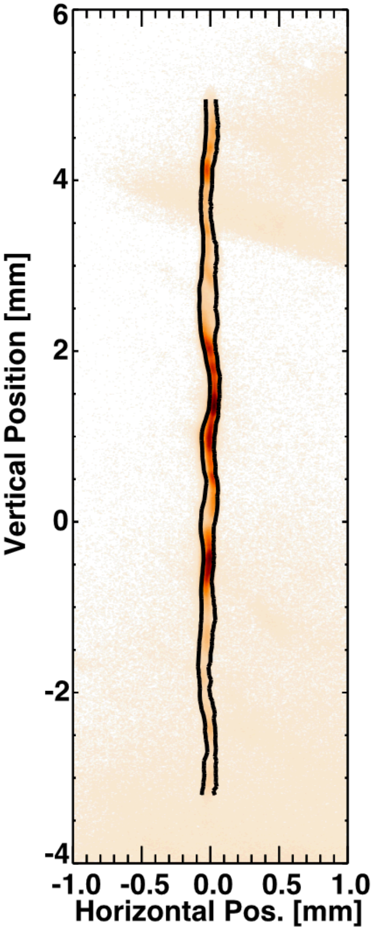
The crystal imager images the continuum emission generated by the compressed deuterium fuel at stagnation.



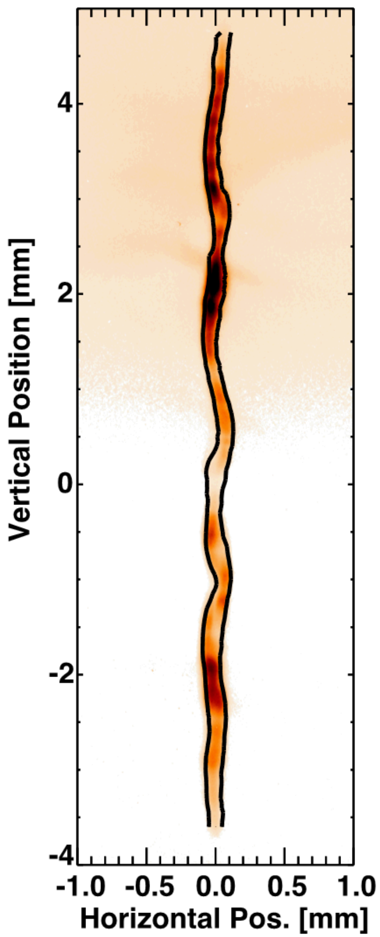
- These time-integrated images are primarily a superposition of 6.2 and 9.4 keV x-rays imaged by n=2 and n=3 Bragg reflections.
- The emission column is narrow and extends over many mm in the vertical direction. The emission undergoes large variations in intensity.

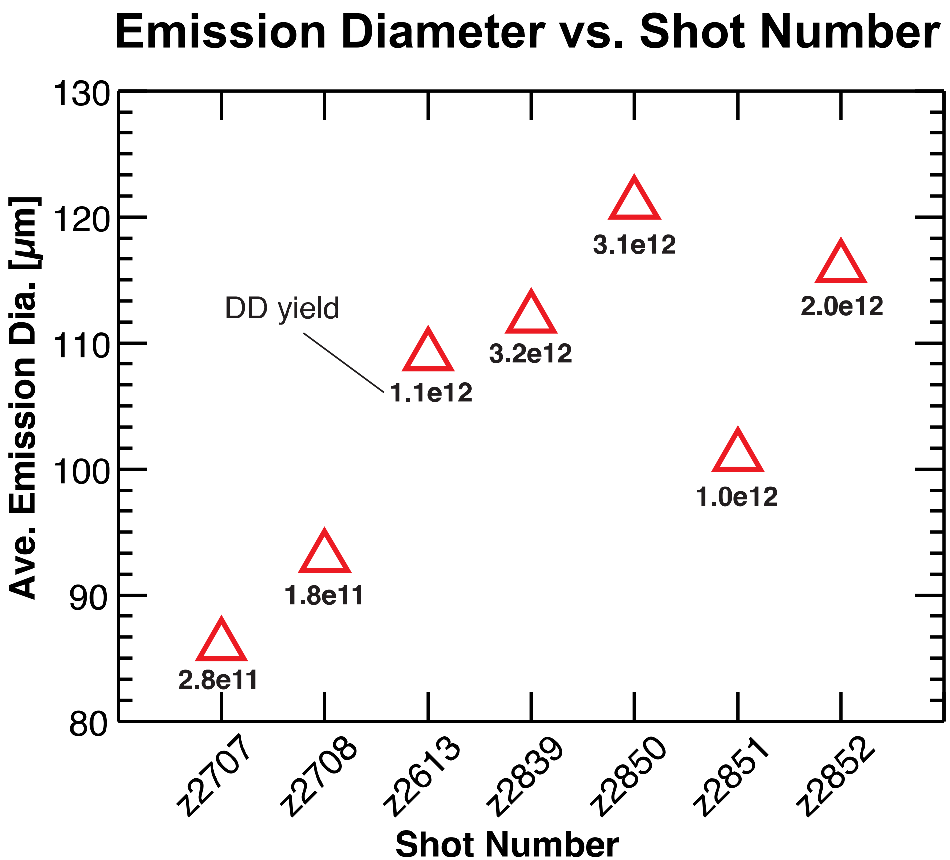
The average emission diameter appears to increase for shots with higher DD neutron yields.* Variations in the axial emission intensity still require an explanation.

z2707
Y_{DD} = 2.8e11



z2839
Y_{DD} = 3.2e12





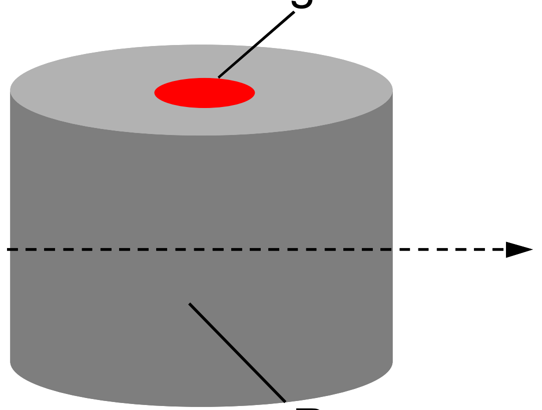
Ray tracing indicates that this small increase in diameter is detectable even though the radial resolution is 60 μm.

*Diameter was defined using a contour that encloses 85% of the signal from the CoM position.

Simple SPECT3D* simulations that included the imager response function, indicate that the emission variations are affected by the liner opacity.

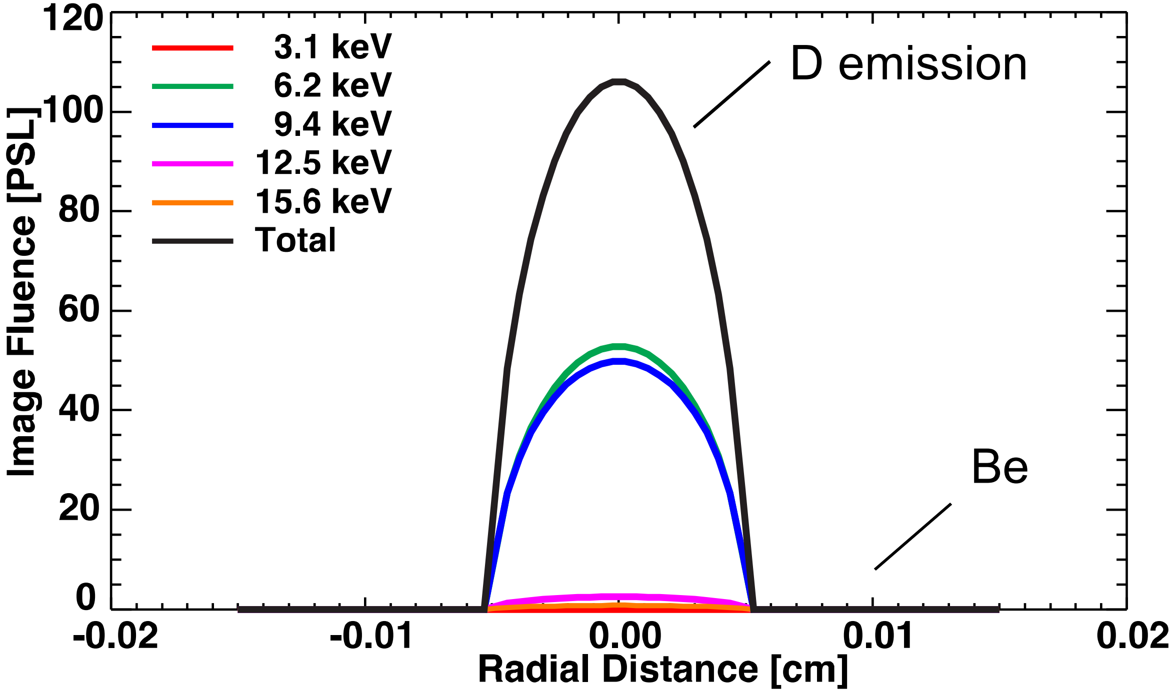
SPECT3D setup

Deuterium core
100 μm dia.
$T_e = T_i = 2.5$ keV
0.4 g/cc



Be
0.5 mm thick
$T_e = T_i = 0.01$ keV
18.5 g/cc

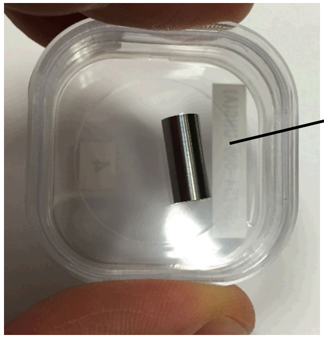
Radial emission profiles from SPECT3D that include the imager response function.



The 6.2 and 9.4 keV contributions are affected by the Be opacity, so bright spots are not necessarily the hottest part of the plasma.

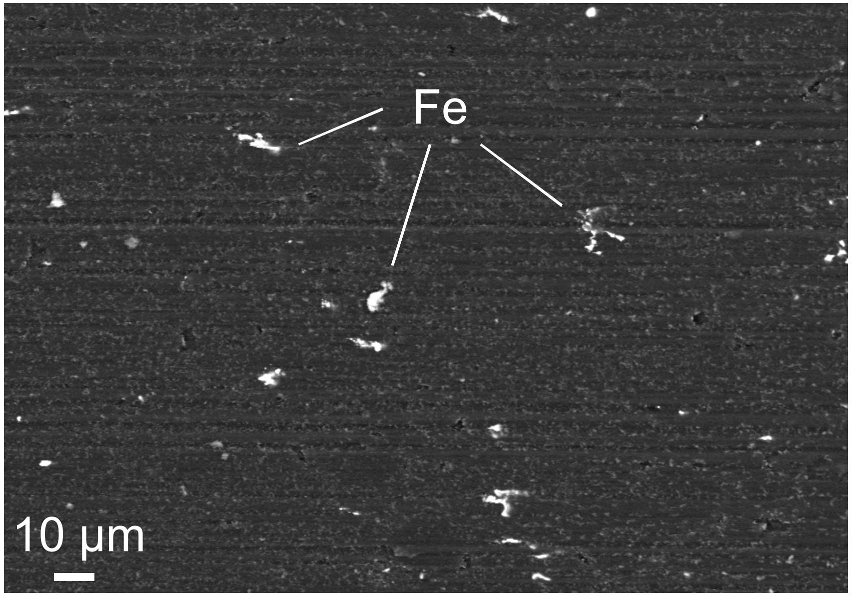
*SPECT3D is a collisional-radiative spectral analysis code produced by Prism Computational Sciences, Inc.

To attempt to explain the intensity variations, a spherical crystal spectrometer was designed to capture Fe spectra in order to infer axial variations of T_e and n_e.



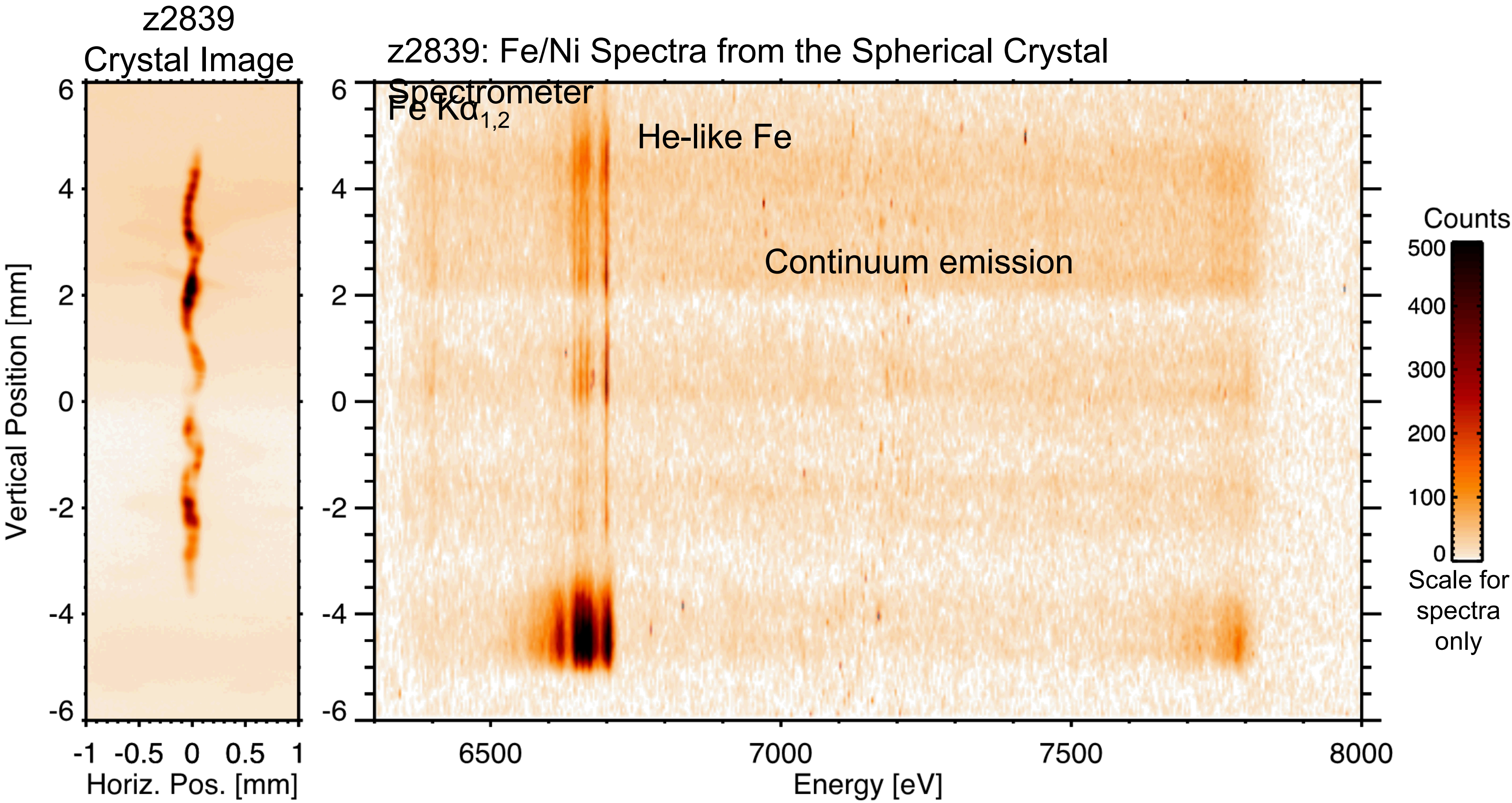
Machined Be liner

SEM image of the Be liner outer surface



- The Be stock material contains 100 ppm (0.01% atomic) of Fe that originate from the manufacturing process.
- The Fe appears as micron-sized impurities that are uniformly distributed on the visible surfaces. We are assuming it is uniform in the bulk.

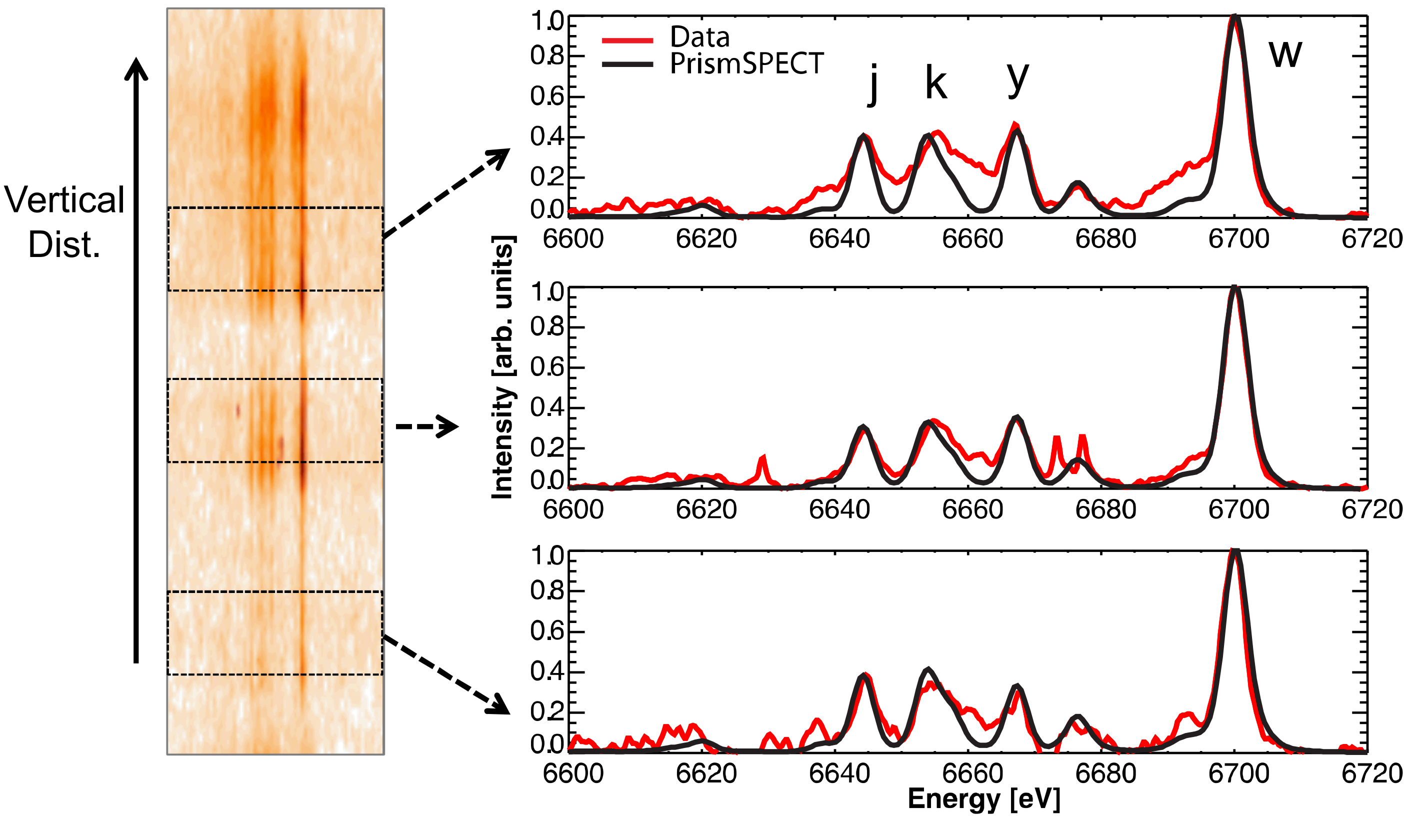
The emission from the He-like Fe charge state (hv = 6.7 keV) was observed. Bright Fe emission appears near the same axial positions as the bright portions of the crystal imager.



The high-resolution Fe spectra enable a measurement of T_e and n_e by fitting simulated spectra to the measured satellite (j,k), intercombination (y) and resonance (w) lines.

Spectral Image

Experimental spectra fitted with PrismSPECT simulations using E/ΔE = 3000.



<u>Inferred values</u>

T_e = 1.5 keV
n_e = 1.2e23 cm^{-3}

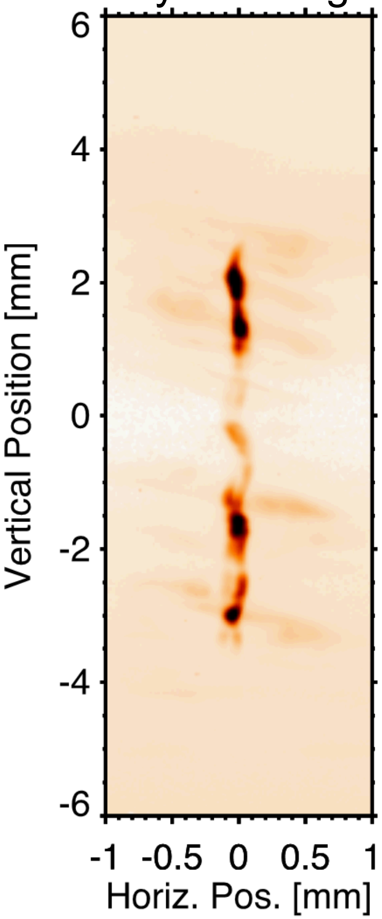
T_e = 1.6 keV
n_e = 1.7e23 cm^{-3}

T_e = 1.4 keV
n_e = 2.0e23 cm^{-3}

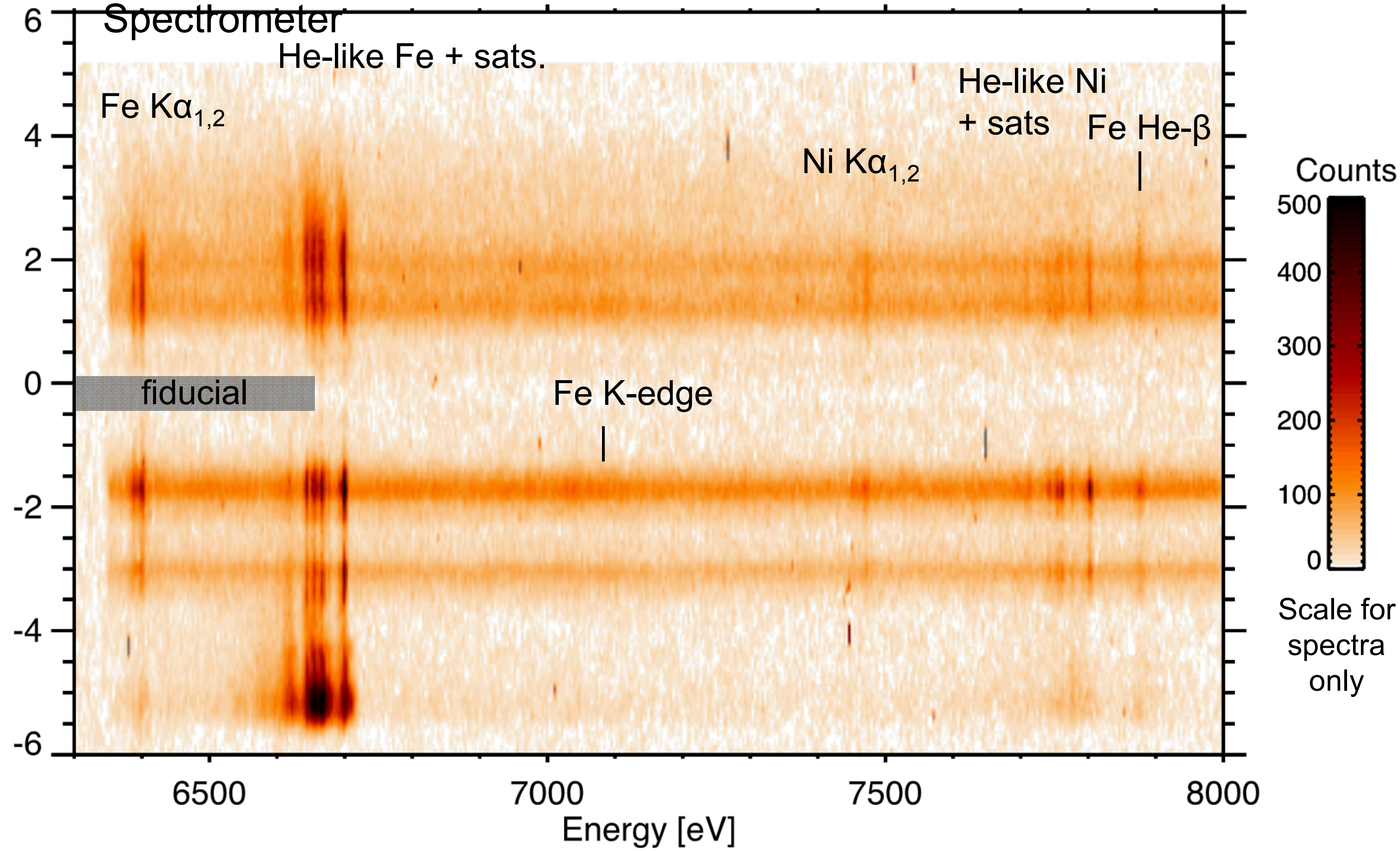
Here the regions of bright Fe emission are lower density suggesting the increased brightness may be related to an elevated fraction of Fe mix.

The sensitivity and energy range were increased on subsequent shots, which revealed He-like Ni emission and the Fe He-β spectral line.

z2850: Crystal Image



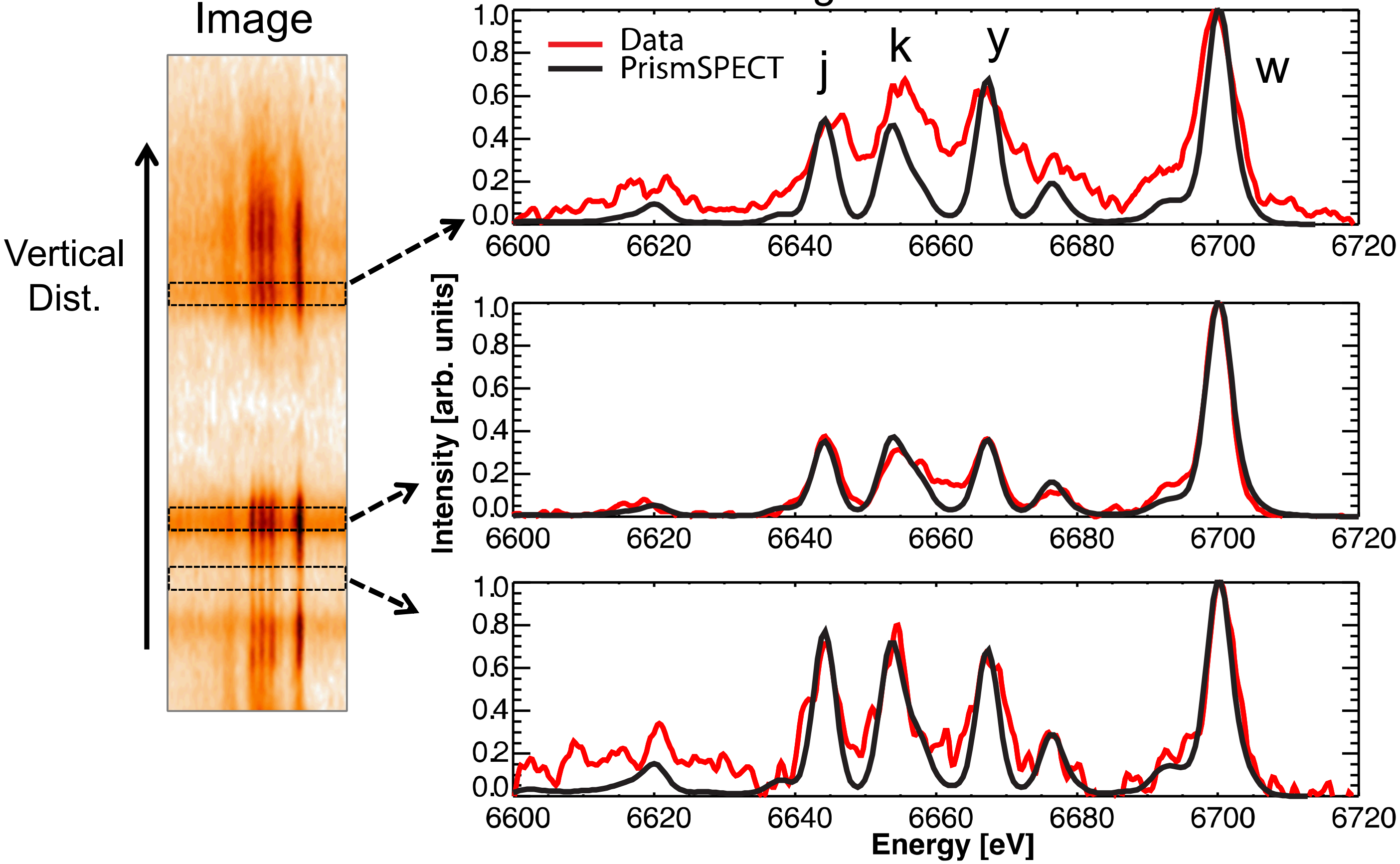
z2850: Fe/Ni Spectra from the Spherical Crystal Spectrometer



Fitting reveals similar T_e and n_e values, but now the dimmer regions are less dense.

Spectral Image

Experimental spectra fitted with PrismSPECT simulations using $E/\Delta E = 3000$.



Inferred values

T_e = 1.6 keV *
n_e = 2.9e22 cm^{-3}
**Fitting accuracy maybe compromised by source broadening.*

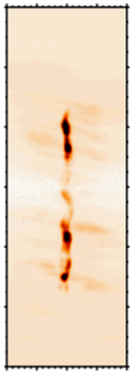
T_e = 1.5 keV
n_e = 1.7e23 cm^{-3}

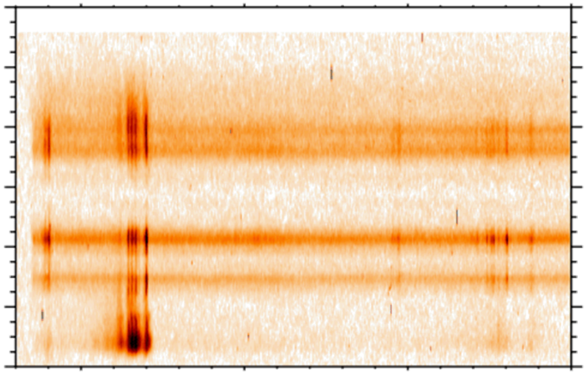
T_e = 1.3 keV
n_e = 2.9e22 cm^{-3}

The large variation in n_e for two adjacent regions suggest that the compression uniformity may need improvement.

Summary: The spherical crystal imager and spectrometer are providing valuable insight into the morphology and conditions of the stagnation plasma.

- The crystal imager provides the size of the stagnation plasma.
- The spectrometer provides a measurement of T_e and n_e.

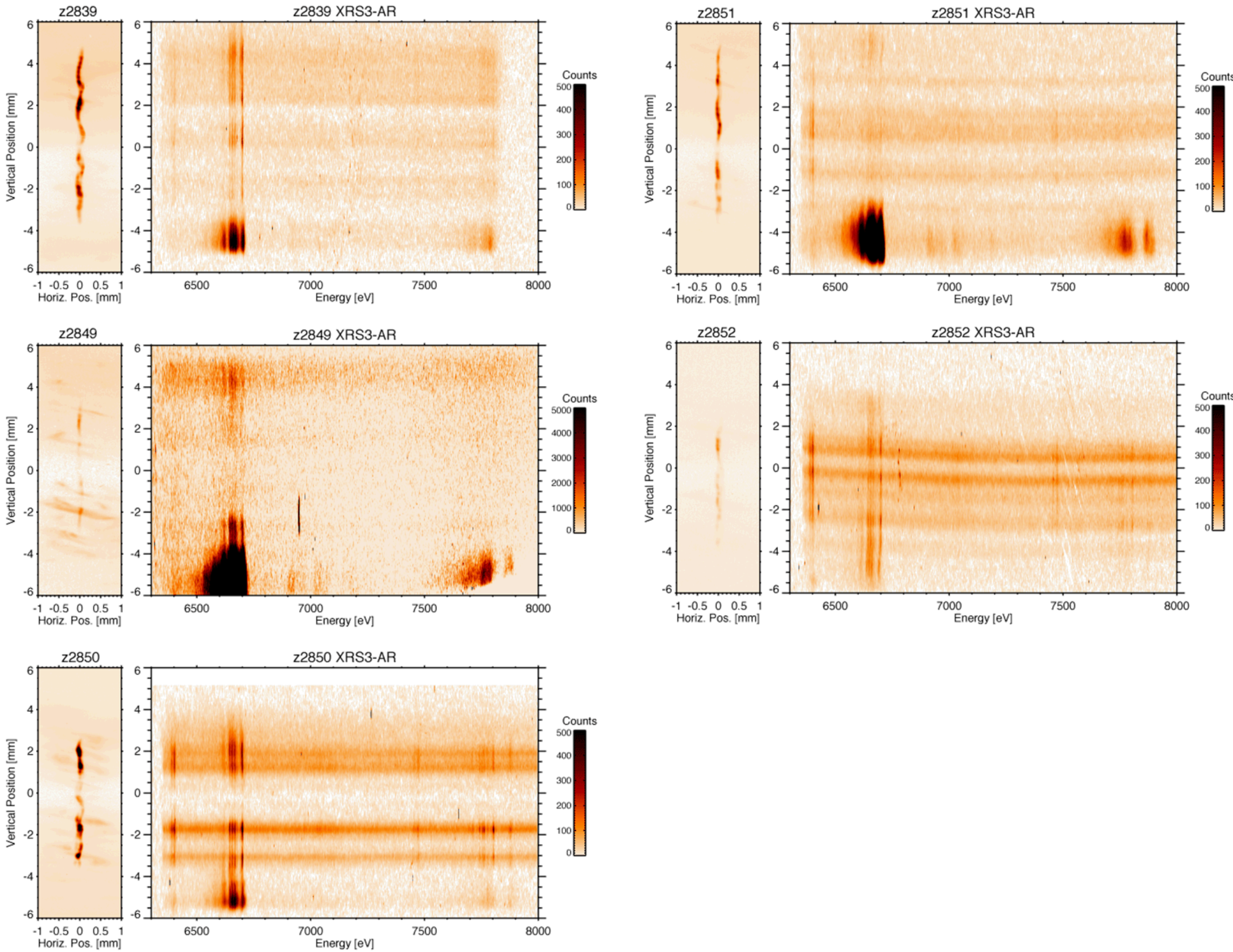




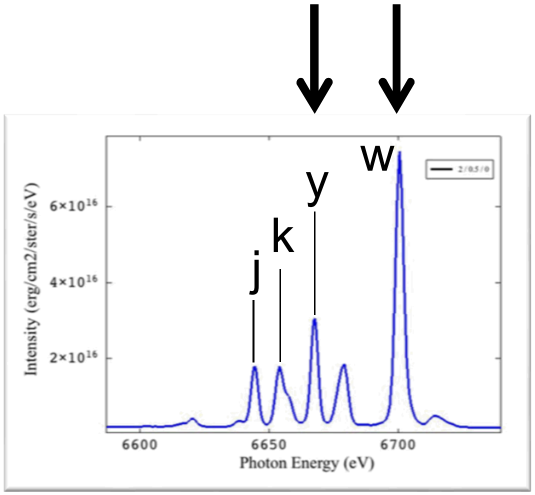
- Future work includes:
  - Absolute calibration of the Fe spectra to measure mix. Also possible to use continuum emission (see S.B. Hansen HEDSA talk).
  - SPECT3D simulations with T_e and n_e gradients.
  - Increase the imager resolution by 2x to 30 μm to better define the width of the column.

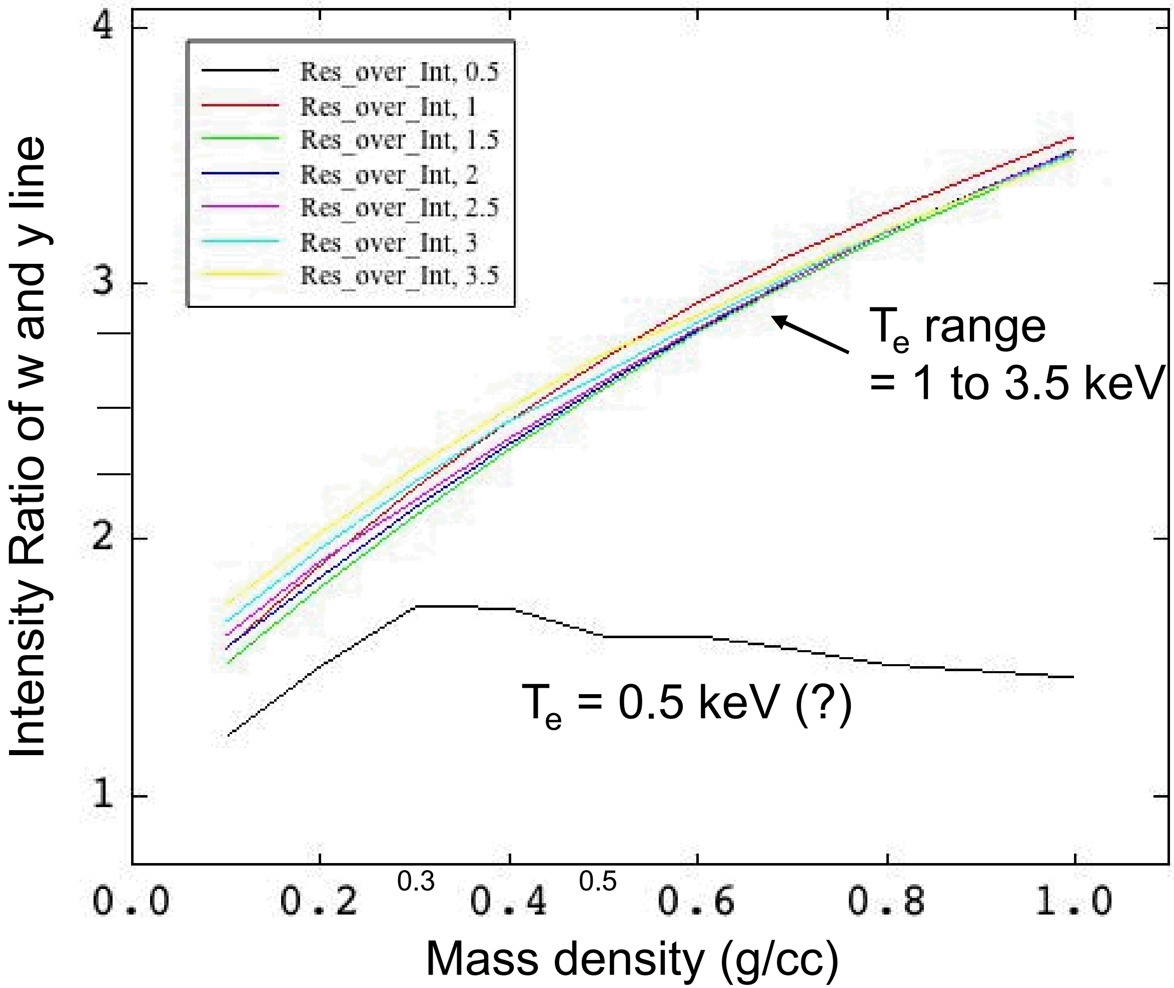
Backups

Snapshot of the processed data.



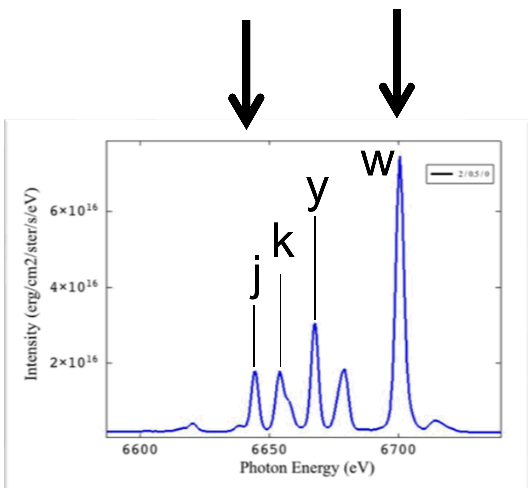
The integrated line intensity ratio of the Fe resonance (w) to intercombination (y) line show sensitivity to fuel density. Fit density first, then temperature.

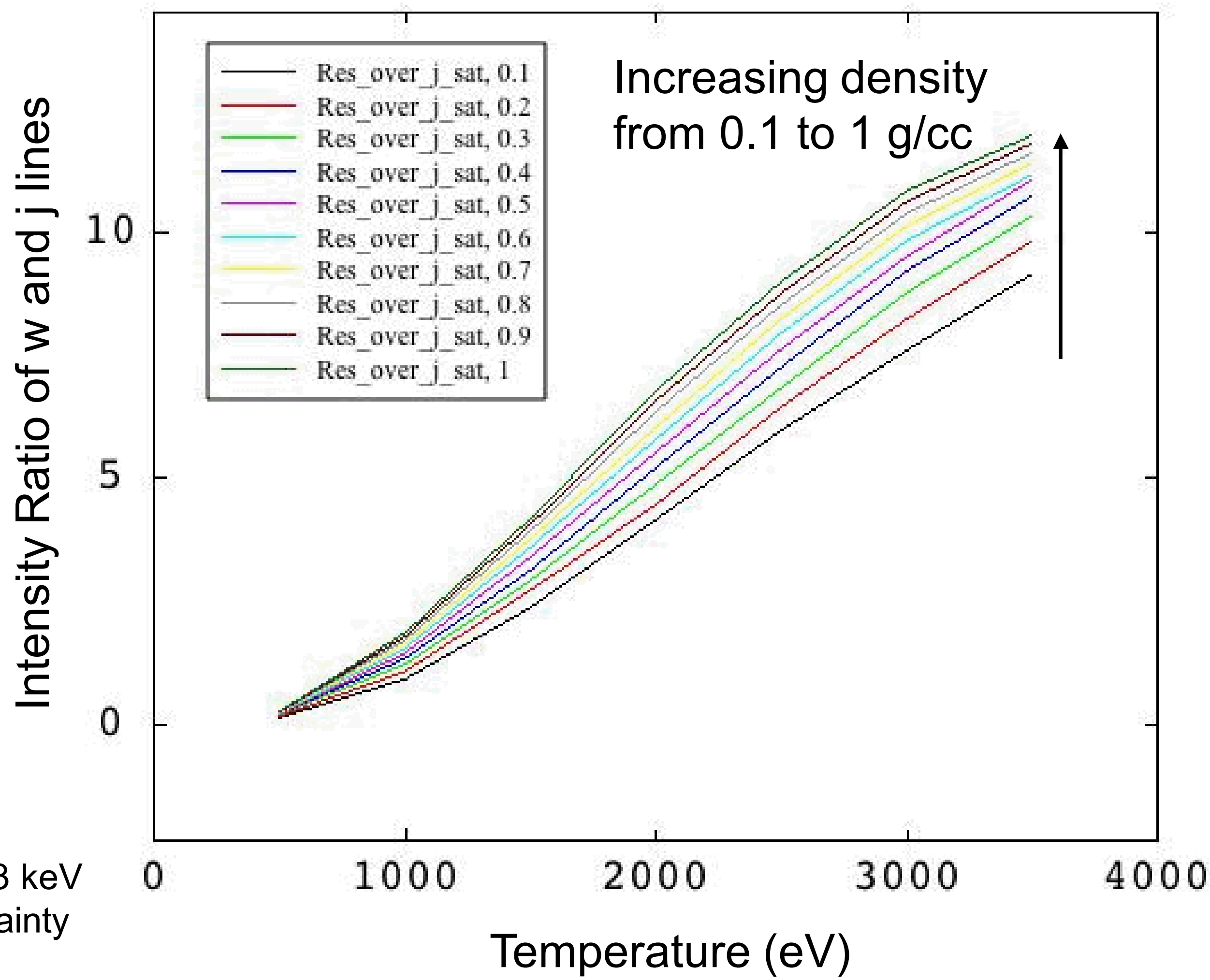




10% uncertainty in line ratio measurement yields 0.4 g/cc +/- 0.1 g/cc (25% uncertainty)

The integrated line intensity ratio of the Fe resonance (w) to satellite line j (or k) show sensitivity to fuel T_e.





10% uncertainty in line ratio measurement yields 2.5 keV +/- 0.3 keV (12% uncertainty) w/density uncertainty included.

The width of the Fe He-beta line shows *some* sensitivity to fuel density. With increases ~ 0.3 eV per 0.1 g/cc. Doppler broadening will also increase the width.