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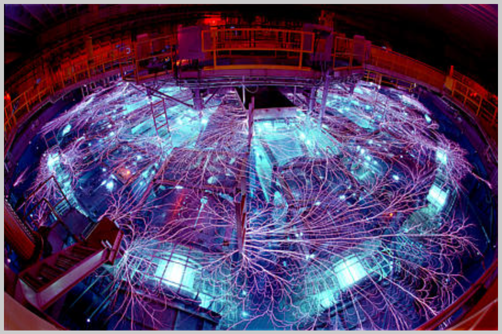

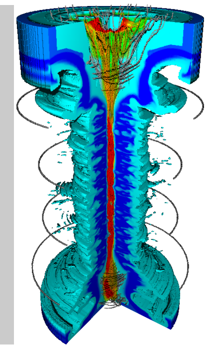

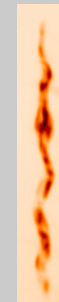

Self-emission crystal imaging and spectroscopy for MagLIF.

E.C. Harding, M.R. Gomez, S. A. Slutz, A.B. Sefkow, M. Geissel, A.J. Harvey-Thompson, M. Schollmeier, K.J. Peterson, T.J. Awe, S.B. Hansen, K.D. Hahn, P.F. Knapp, P.F. Schmit, C.L. Ruiz, D.B. Sinars, C.A. Jennings, I.C. Smith, D.C. Rovang, G.A. Chandler, M.R. Martin, R.D. McBride, J.L. Porter, and G.A. Rochau

Sandia National Laboratories, Albuquerque, NM

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The development of the Magnetized Liner Inertial Fusion (MagLIF) concept has motivated the development of new diagnostics.[1]

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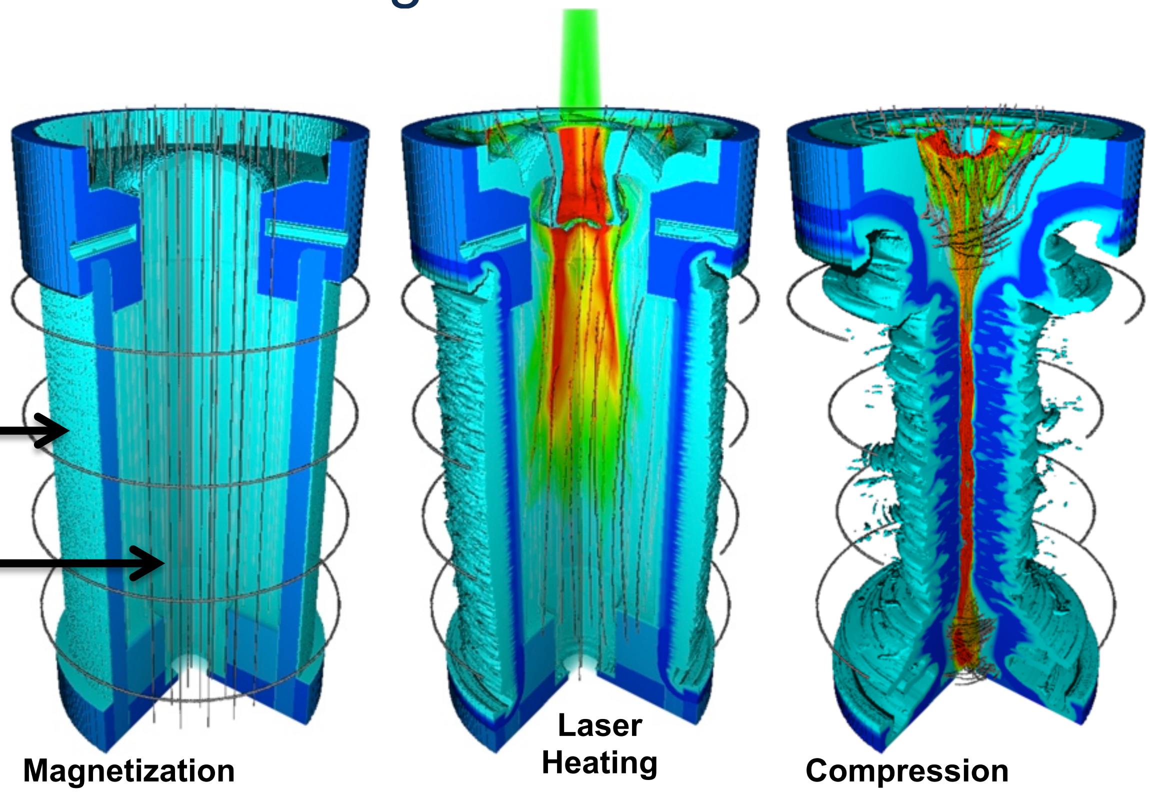
Imploding Be liner

Gaseous D_2 fuel 60 psia



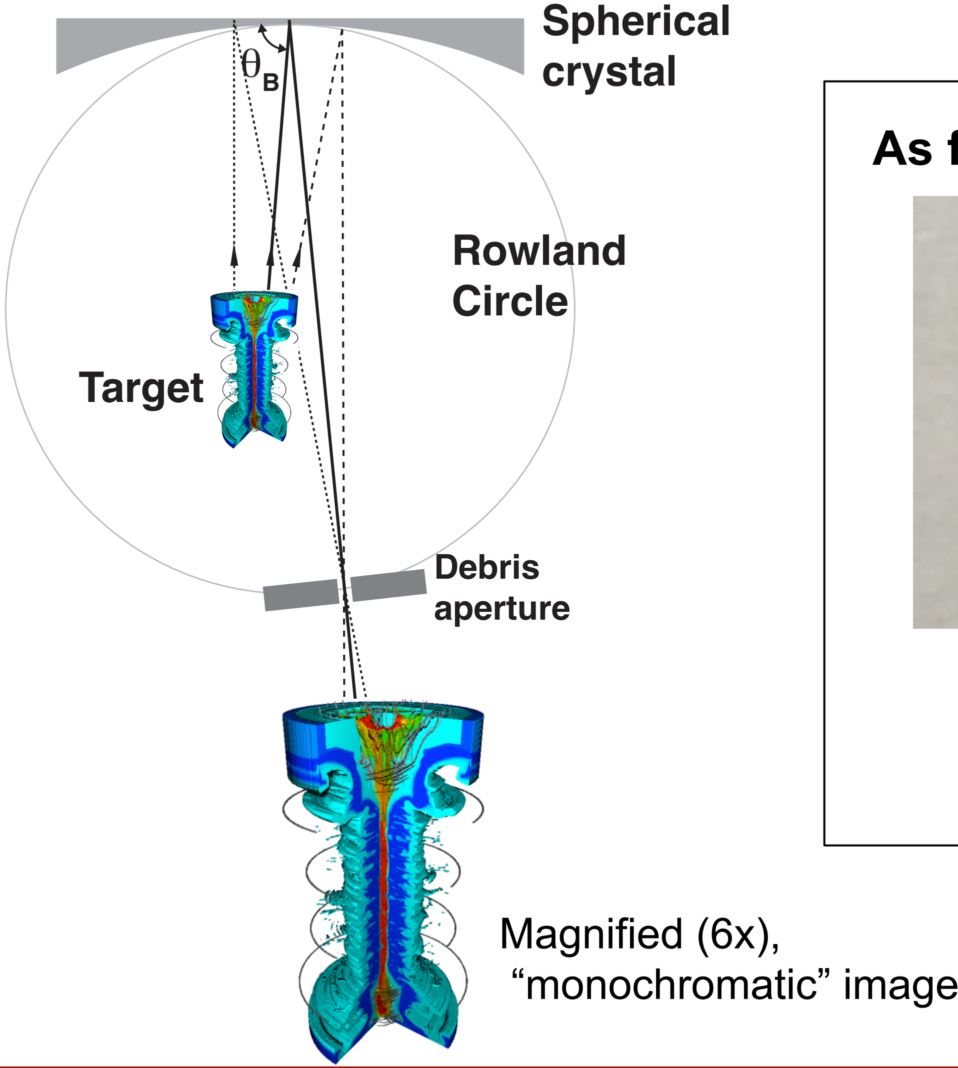
Diagnose laser preheated fuel

Diagnose compressed, hot fuel

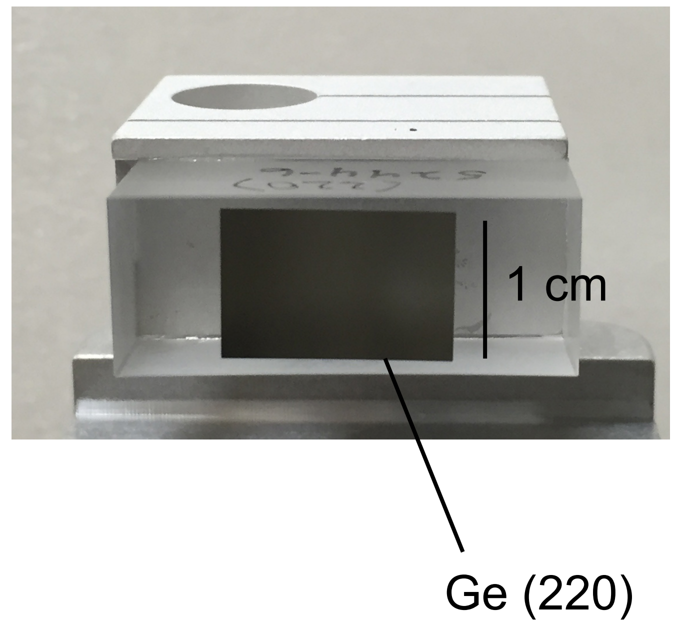
[1]M.R. Gomez et. al., Phys. Rev. Letters (2014)
Graphic by C.A. Jennings

We use spherically bent crystal optics to image the x-ray, self-emission from our MagLIF targets.

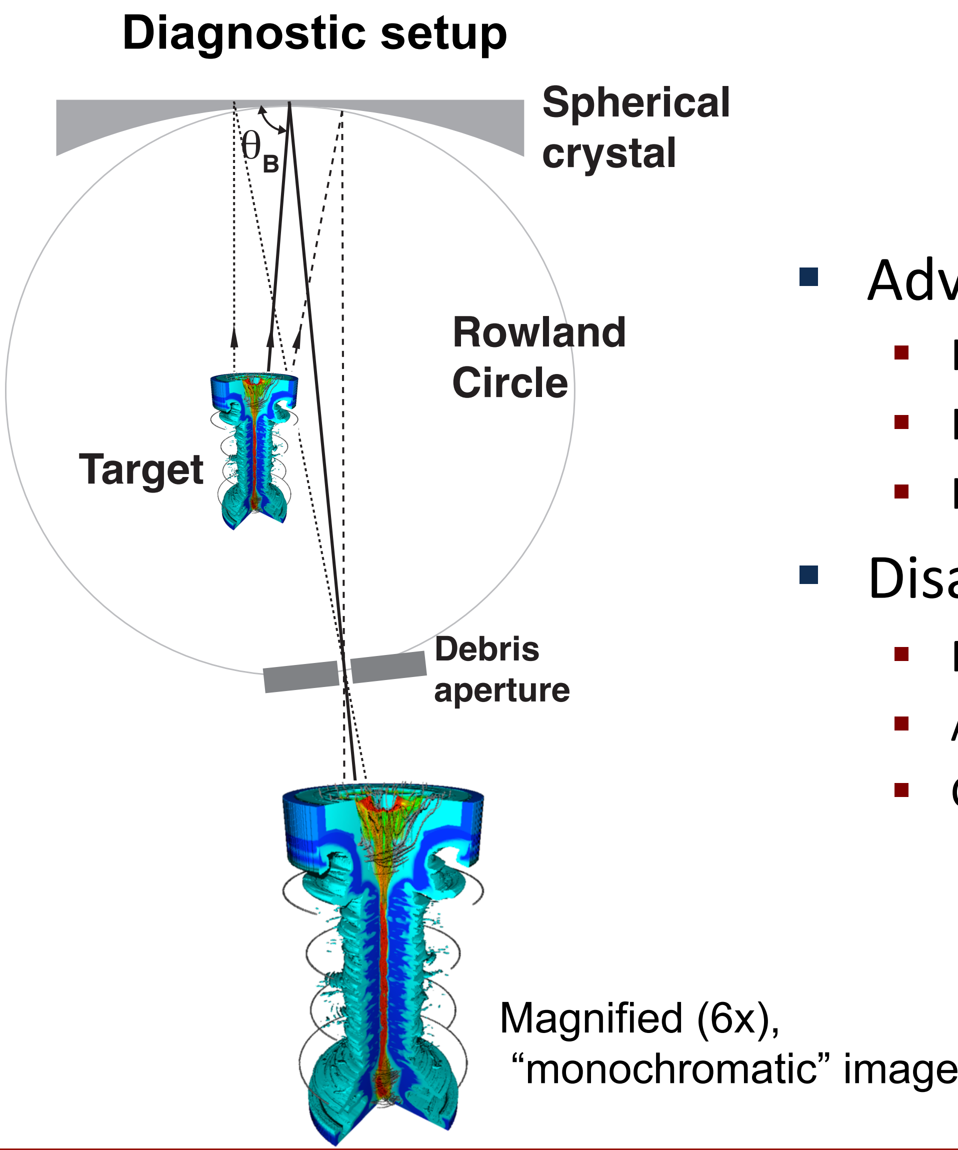
Diagnostic setup



As fielded, spherically bent crystal



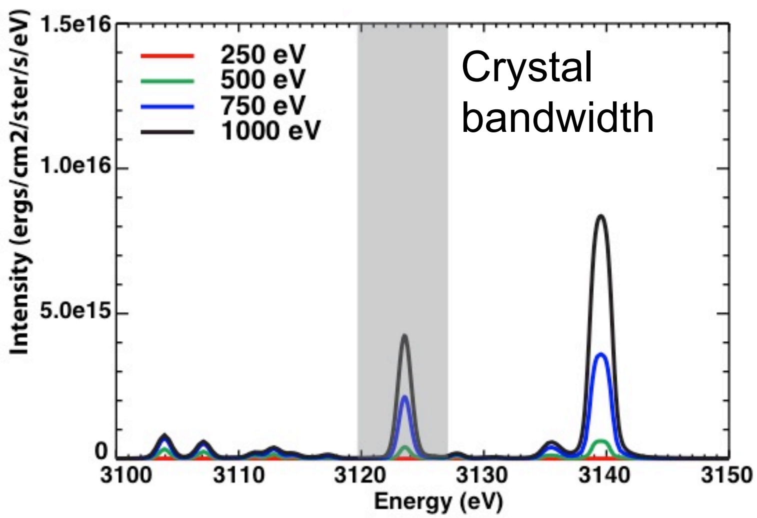
We use spherically bent crystal optics to image the x-ray, self-emission from our MagLIF targets.



- Advantages of crystal imaging:
  - Image energy range is well-defined
  - High-sensitivity rel. to pinholes
  - Increased detector survivability
- Disadvantages of crystal imaging:
  - Field-view limited by crystal size
  - Astigmatism limits the spatial resolution
  - Crystals are not cheap & are fragile

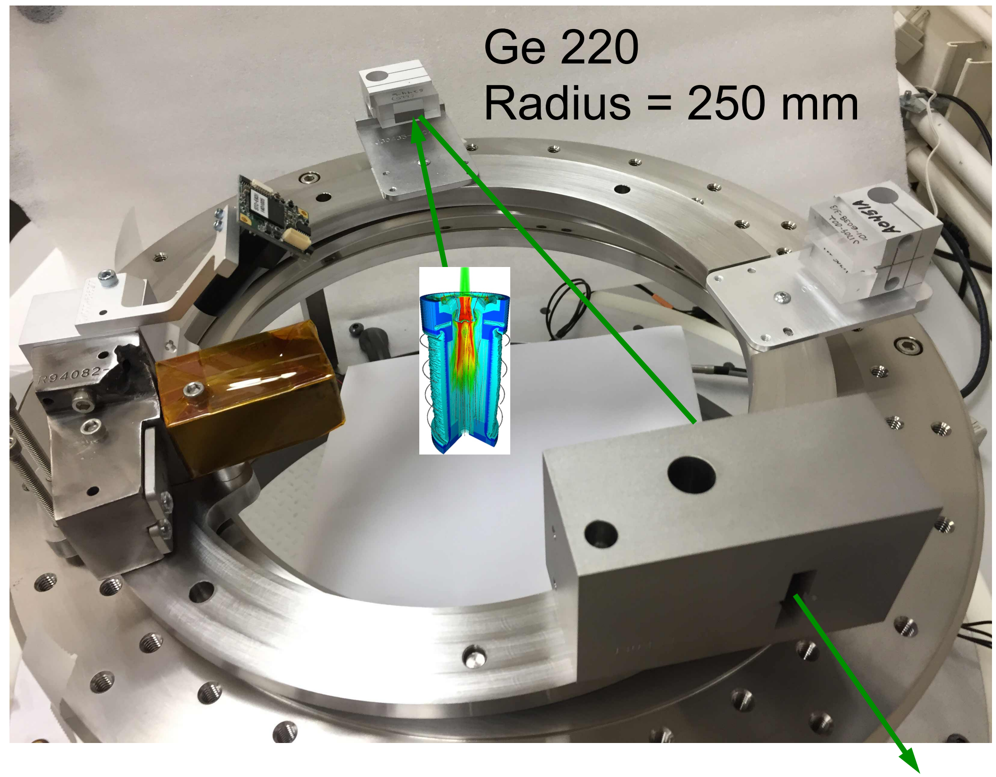
Our crystal imager was designed to selectively image the Ar K-shell line at 3.12 keV. Images are time integrated.

Expected Ar emission spectra from preheated fuel



Higher energy reflections also occur at n x 3.12 keV where n=1,2,3….

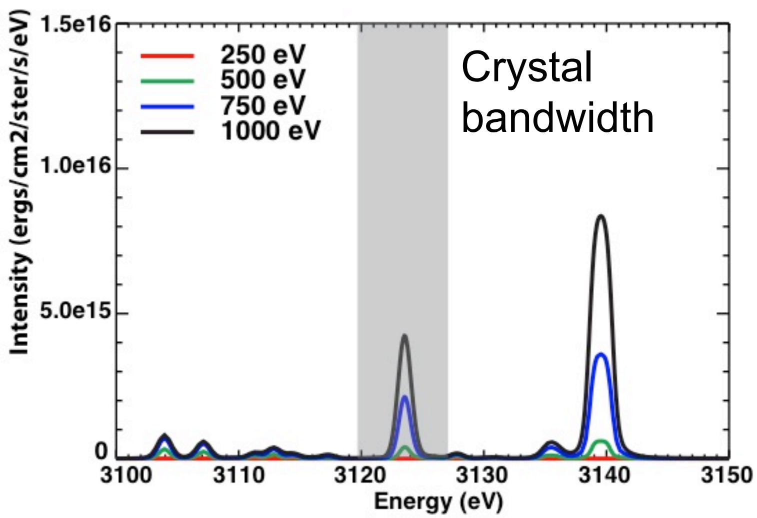
Spherical crystal imager



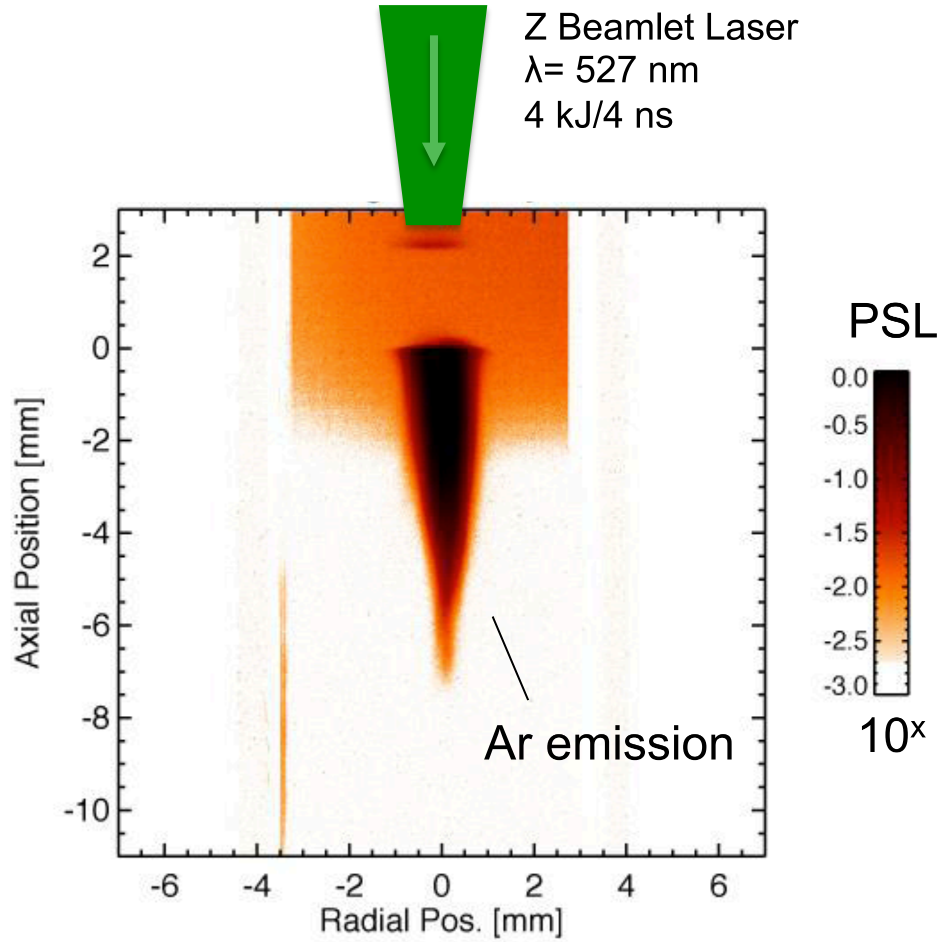
Detector: Fuji TR Image Plate
Located 85 cm from crystal

Our crystal imager was designed to selectively image the Ar K-shell line at 3.12 keV. Images are time integrated.

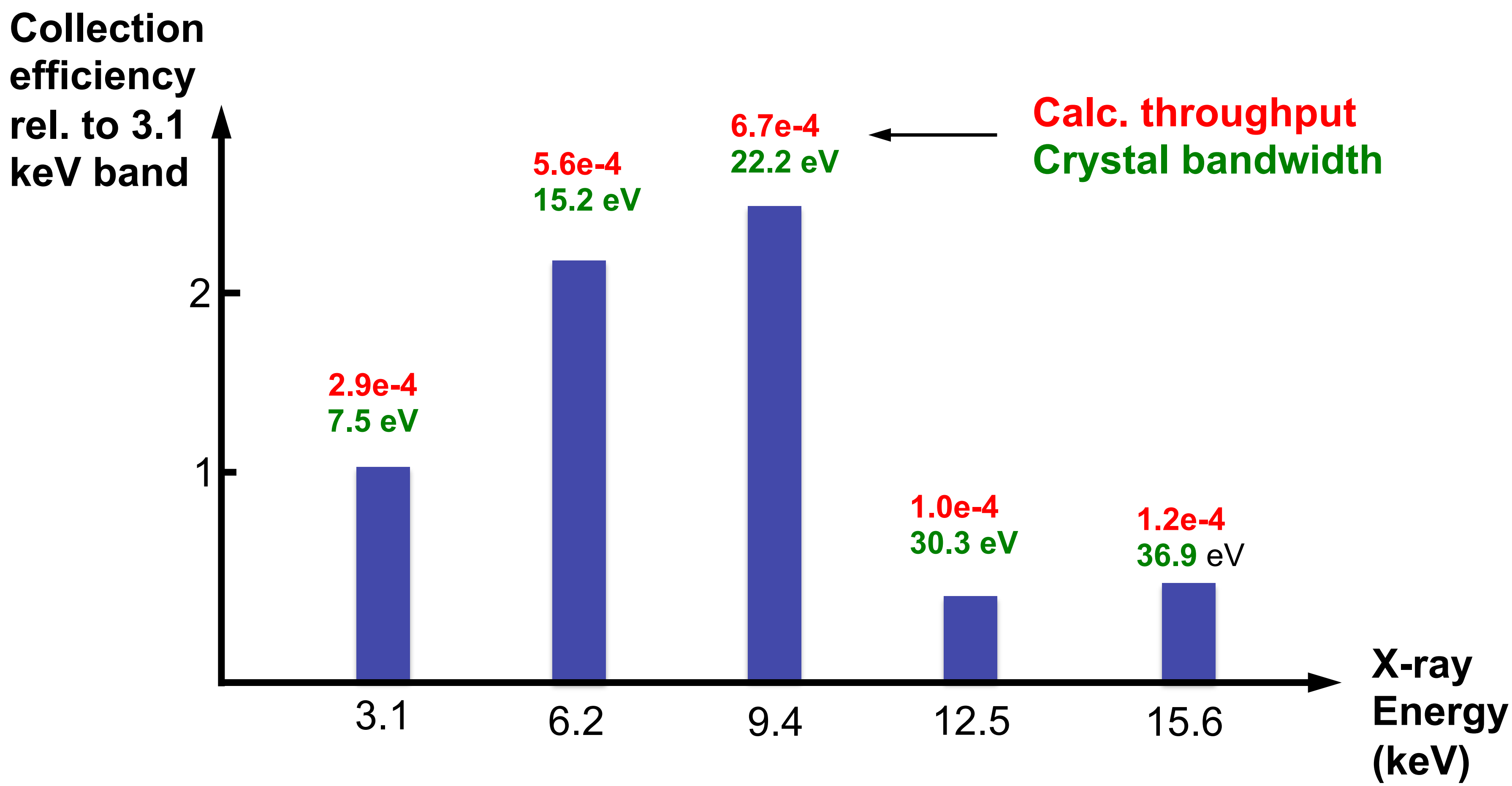
Expected Ar emission spectra from preheated fuel



Higher energy reflections also occur at n x 3.12 keV where n=1,2,3….



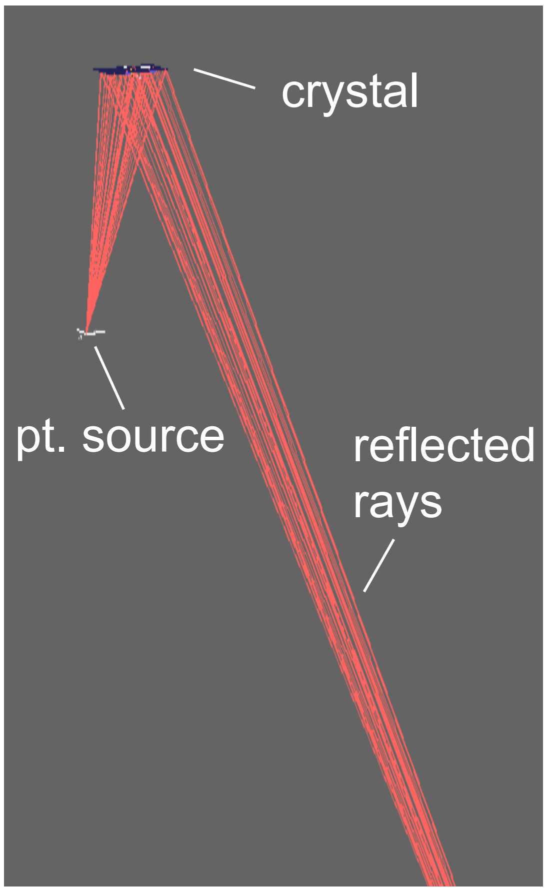
The absolute sensitivity for each energy band was estimated by calculating the total instrument throughput using calculated crystal reflectivities.*



*The throughput estimates include filtering and the image plate response.
Reflectivity curves are calculated using the XOP software routines (M. Sanchez del Rio, SPIE 2011)

The spatial resolution is limited by astigmatic nature of the off-axis imaging. The resolution was estimated using the SHADOW* ray tracing code.

Ray Tracing w/SHADOW



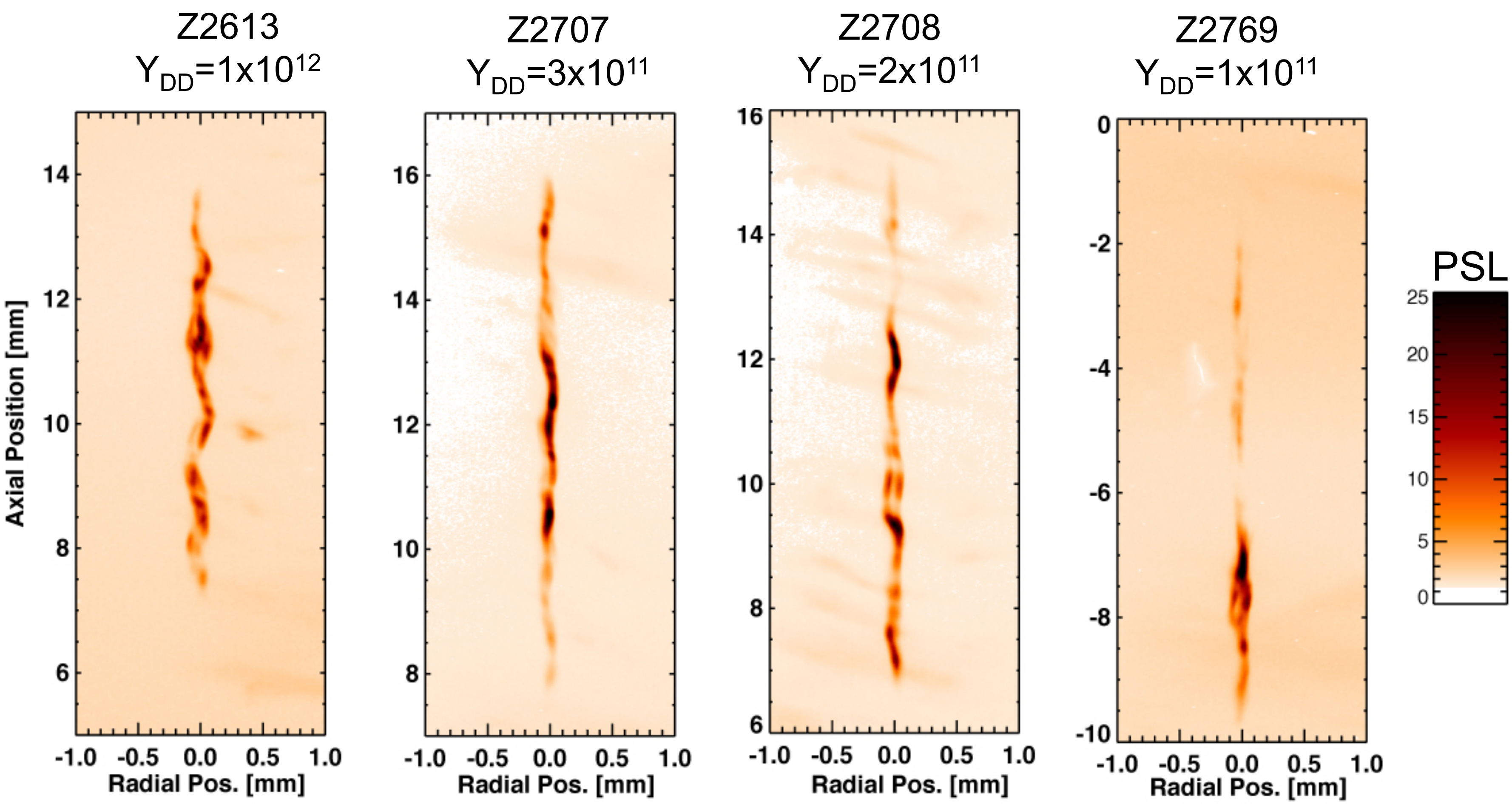
*M. Sanchez del Rio, SPIE 2011

Spatial Resolution Estimates

	Ar emission (δE = 1.3 eV)	Continuum emission
Vertical resolution	**84 µm**	**84 µm**
Horizontal resolution	**16 µm**	**60 µm**

- **Continuum emission**: resolution improves in both directions with a smaller crystal.
- **Line emission:** Vertical resolution will primarily improve with a smaller crystal.

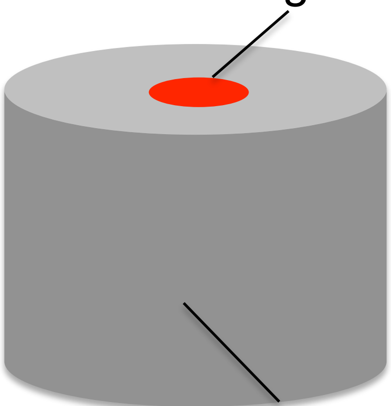
The continuum emission generated during the liner stagnation shows complex structure and non-uniformity in the vertical direction.



The average, radial width is around 100 μm, which is approaching the diagnostic limit of 60 μm.

Simple SPECT3D* simulations indicate the stagnation images are primarily a superposition of 6.2 and 9.4 keV emission.

SPECT3D setup

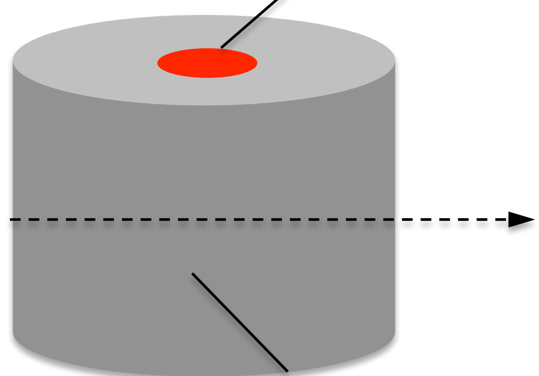


*SPECT3D is a collisional-radiative spectral analysis code produced by Prism Computational Sciences, Inc.

Simple SPECT3D* simulations indicate the stagnation images are primarily a superposition of 6.2 and 9.4 keV emission.

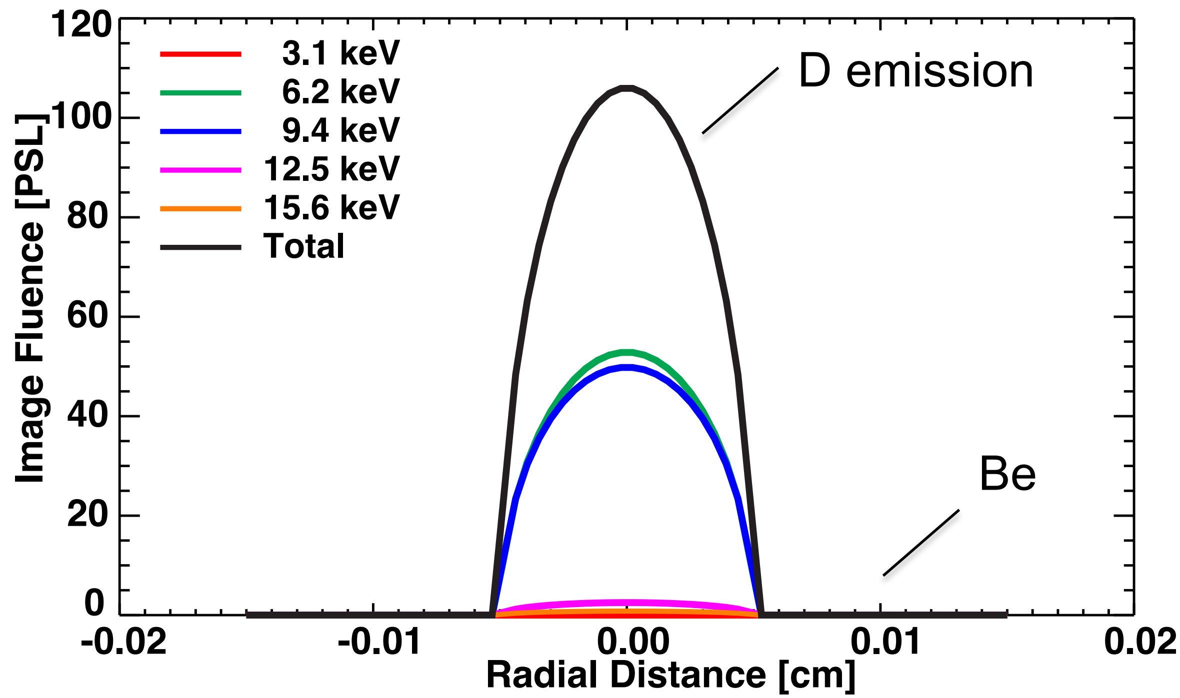
SPECT3D setup

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

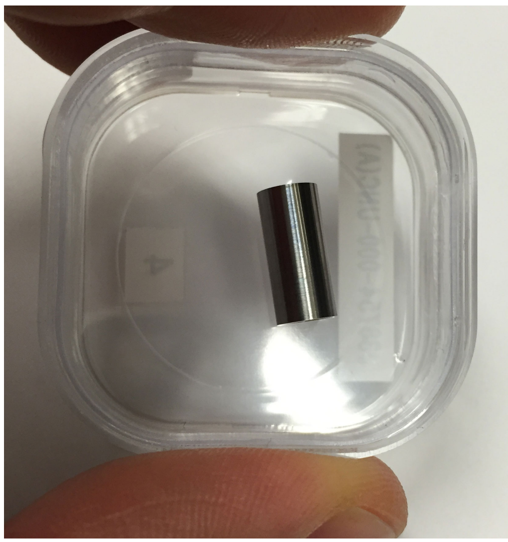
Radial emission profiles from SPECT3D

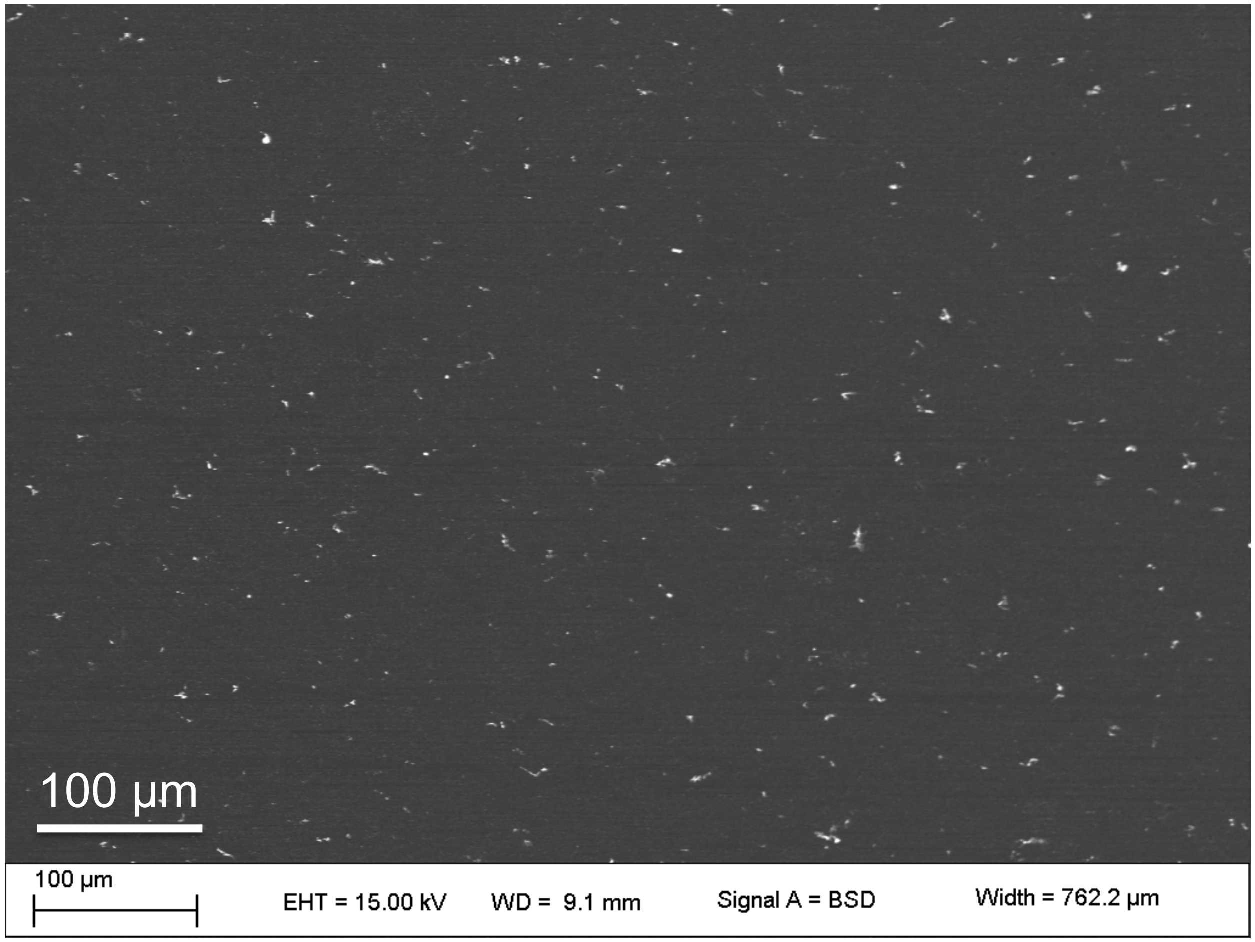


Because the 6.2 keV contribution is significantly affected by the Be opacity the emission variations maybe stability related.

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

Iron impurities occur in our Be targets as micron-sized particles that appear to be uniformly distributed.

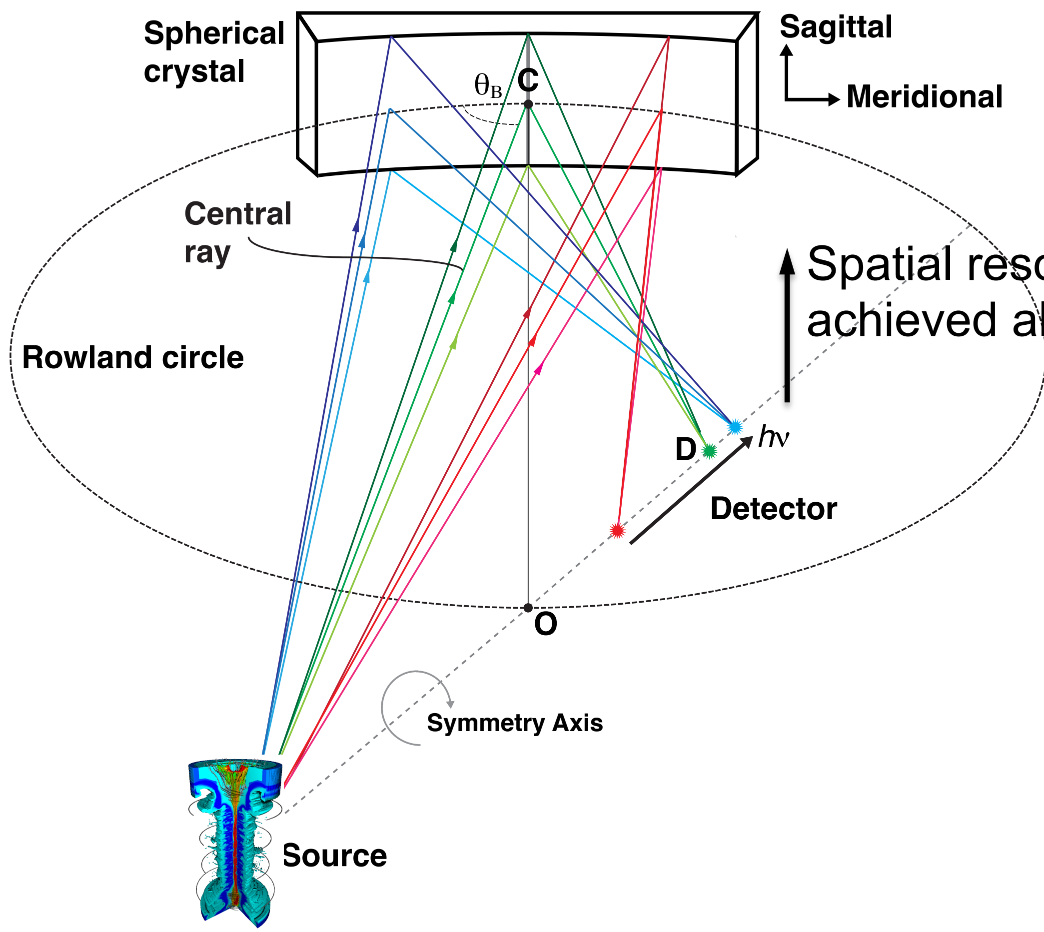




The bright specks are Fe particles embedded in Be (Materion,S-65 grade).
Fe impurity level is ~ **100 ppm** as measured by Materion with ICPS.

To resolve the Fe emission generated at stagnation we use a spherically-bent crystal spectrometer.

Spherical crystal spectrometer[1]



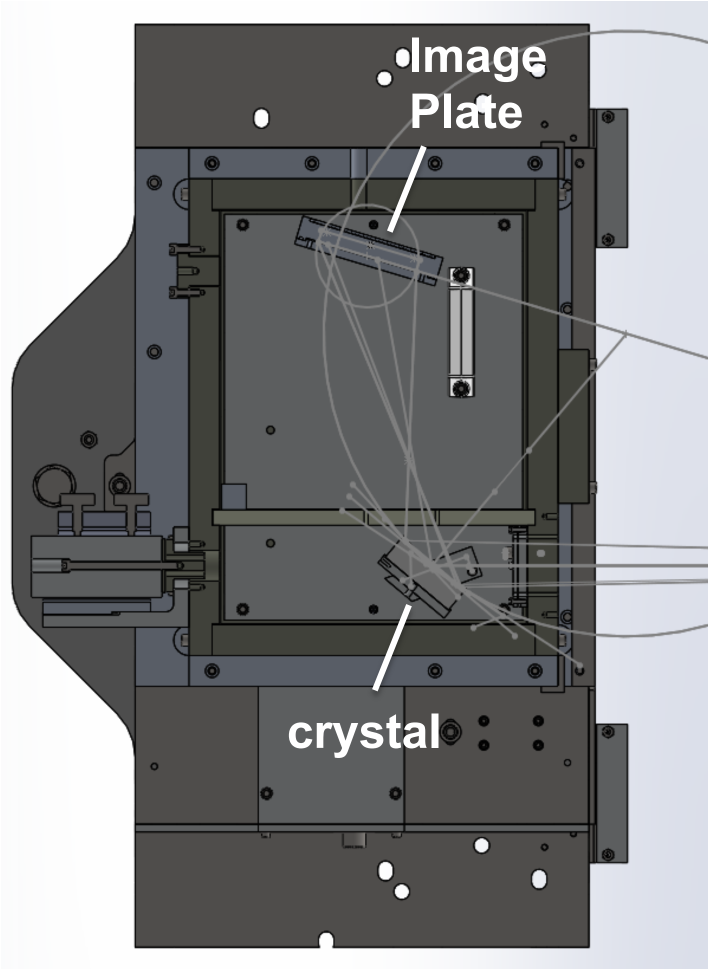
Spatial resolution is achieved along this axis

[1]E.C.Harding et. al., RSI (2015)
D. Sinars et. al. JSQRT (2006)
FSSR used on dynamic hohlraum capsule implosions

The existing XRS[3] spectrometer was optimized for the detection of the weak He-like Fe emission, while maintaining high-spectral resolution.

Spectrometer setup for He-like Fe emission

Crystal	Q20-23 (2d = 2.749 Å)
Source-to-crystal	800 mm
Crystal-to-detector	256.92 mm
Crystal Radius	250 mm
Center Bragg Angle	40°
Crystal size[1]	60 x 36 mm
Spectral Range[2]	6328 - 7977 eV
Spatial Mag. (M_{sag})	0.30x
Spectral Resolution[3]	2 eV
Spatial Resolution[3]	210 μm
Throughput	1.9e-7 steradians



[1]This is a tiled crystal consisting of 2 strips, each one is 60 x 18 mm
[2]Detector length must be 85 mm to capture entire spectral range.
[3]Limited by the Image Plate resolution of 63 microns.

We believe we are observing He-like Fe emission from stagnation. The crystal image and spectra can be aligned using the spatial fiducials attached to the target.

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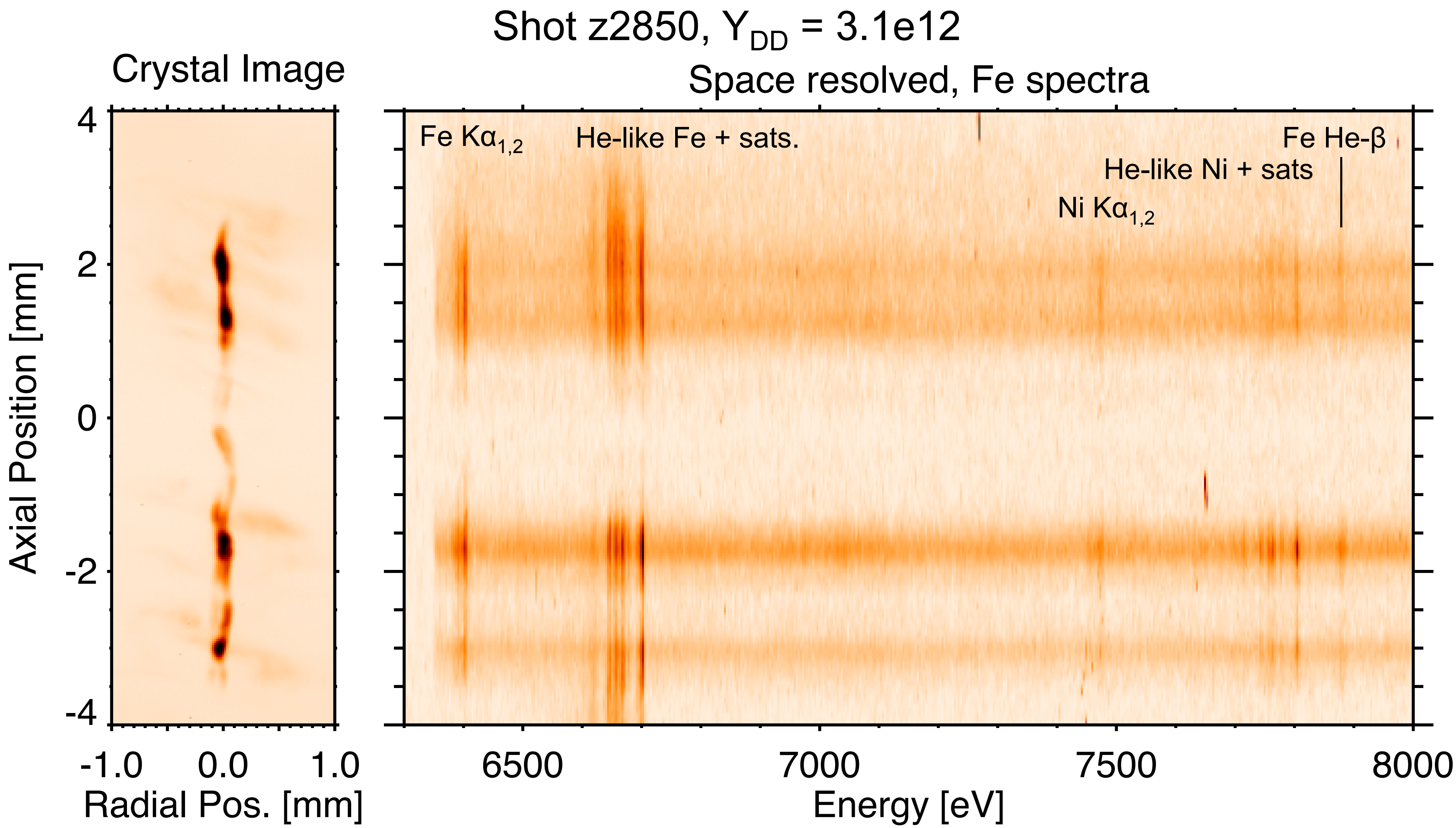

The Fe He-like emission can be fit with synthetic spectra from PrismSPECT to estimate T_e and n_e.

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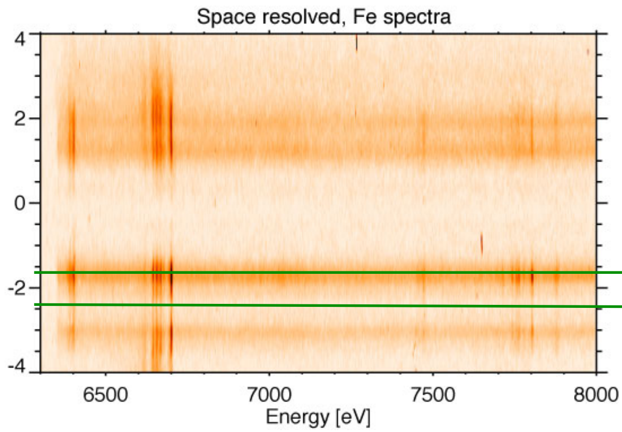
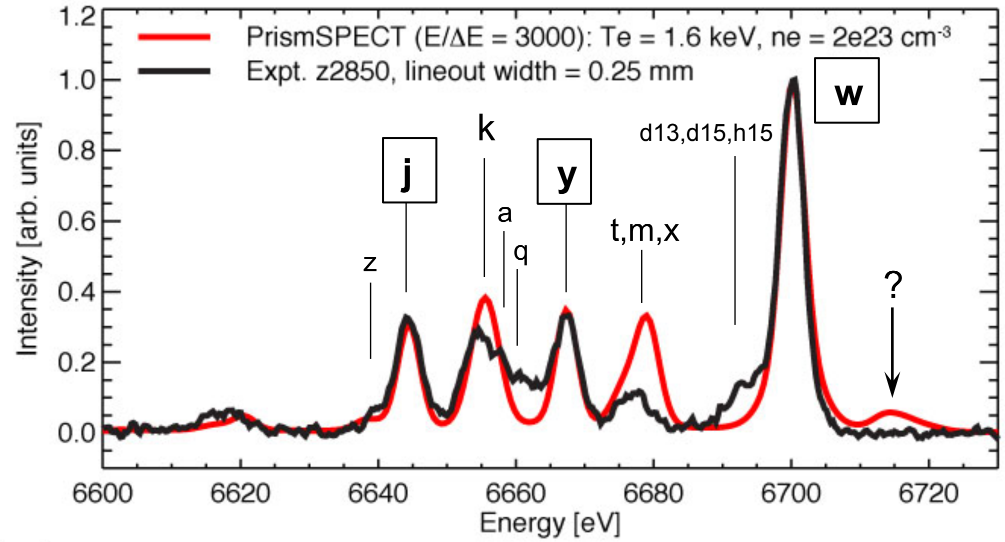
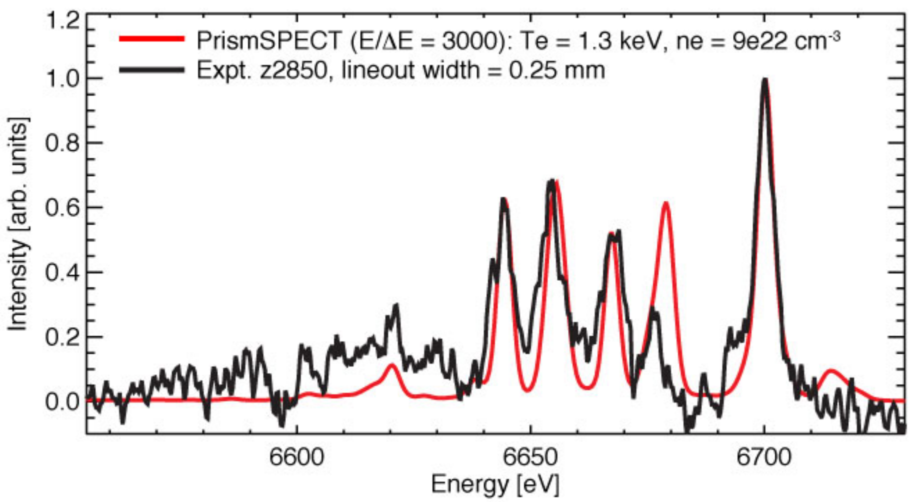


T_e = 1.6 keV, n_e = 2e23 cm^{-3}



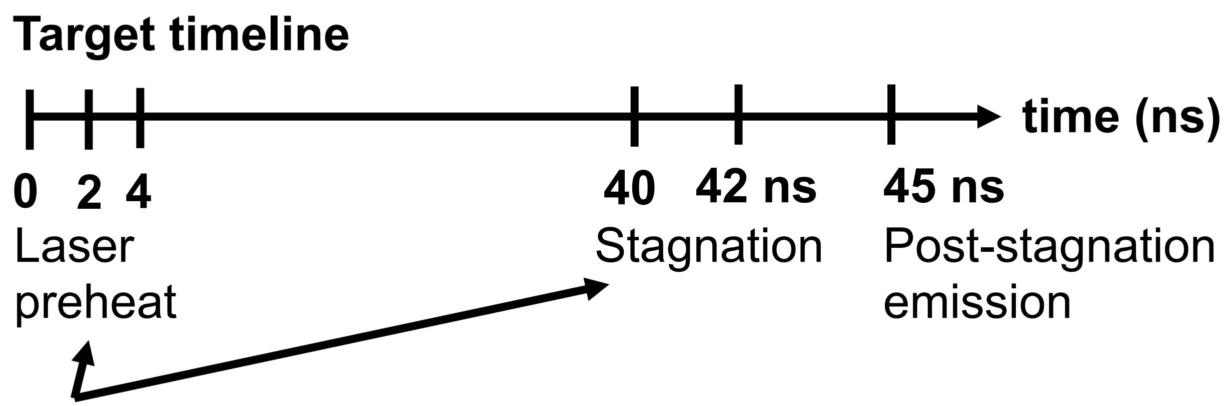
T_e = 1.3 keV, n_e = 9e22 cm^{-3}



Note: Prism calculations are 1D, nLTE, steady-state, and assume 10% Be mix with .001% Fe. Optical depth of Fe w-line ~ 0.1 to 0.2 ODs.

A time-gated detector is needed to further increase the accuracy with which we can interpret the image and spectral data.

- The MagLIF platform requires only modest time resolution to have an impact on our understanding.

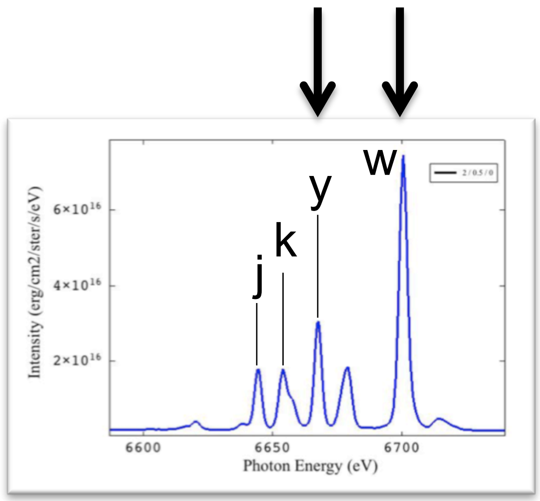


(a) Time gating could be used to separate x-ray emission from these events.
(b) 1 ns with 8 frames could coarsely resolve each event. This will help constrain non-steady calculations.

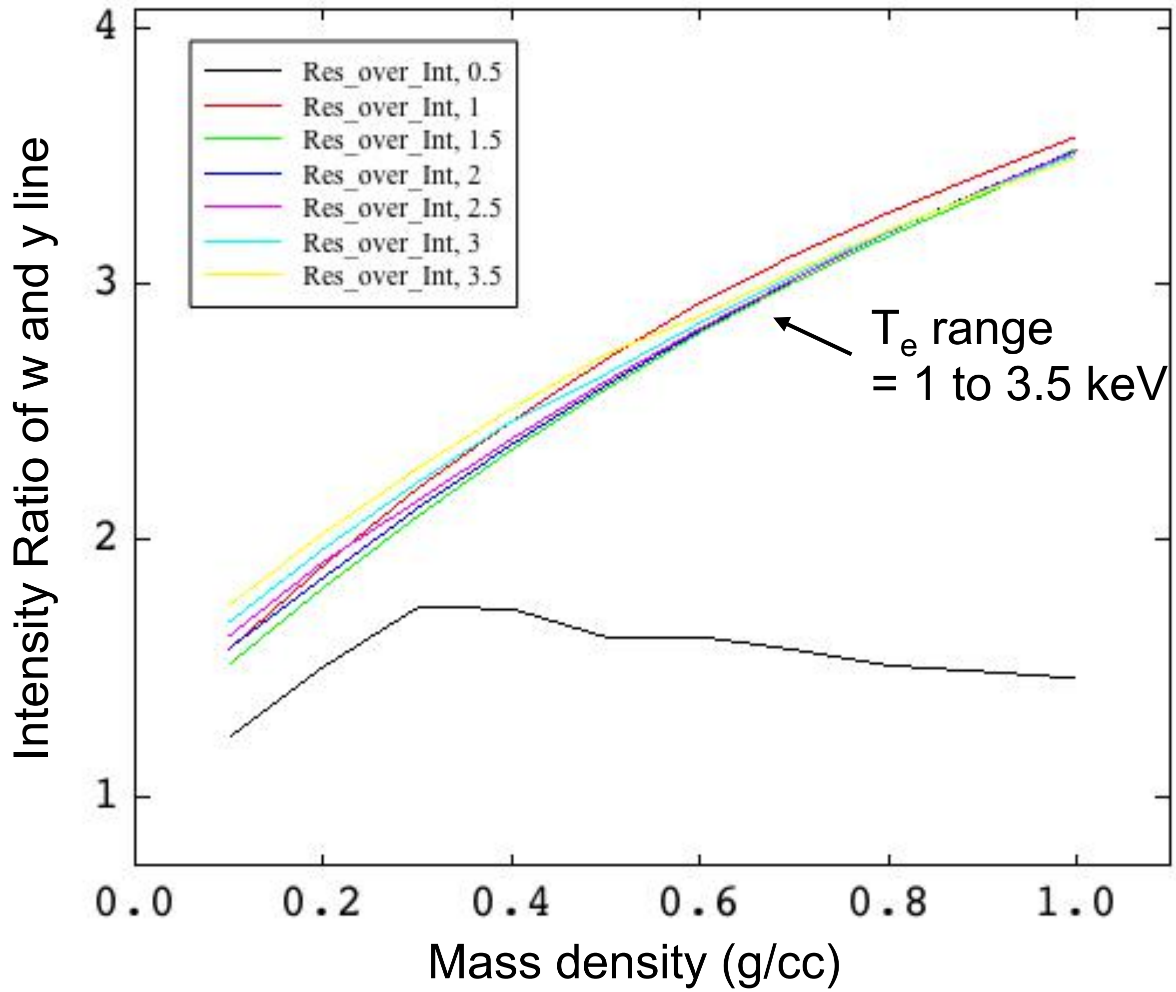
- Ultimately, 0.25 ns resolution is required to fully resolve stagnation.

Backups

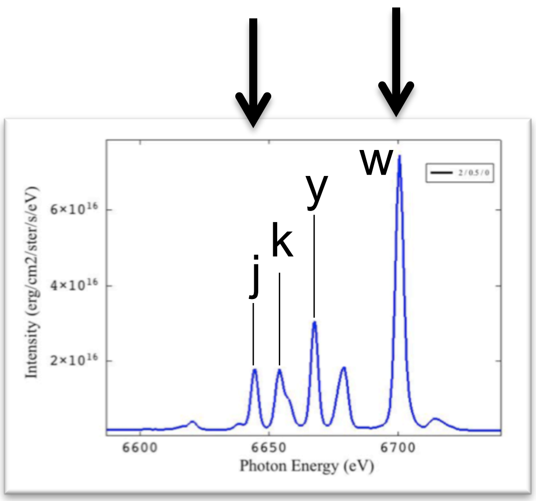
The integrated line intensity ratio of the Fe resonance (w) to intercombination (y) line show sensitivity to fuel density.

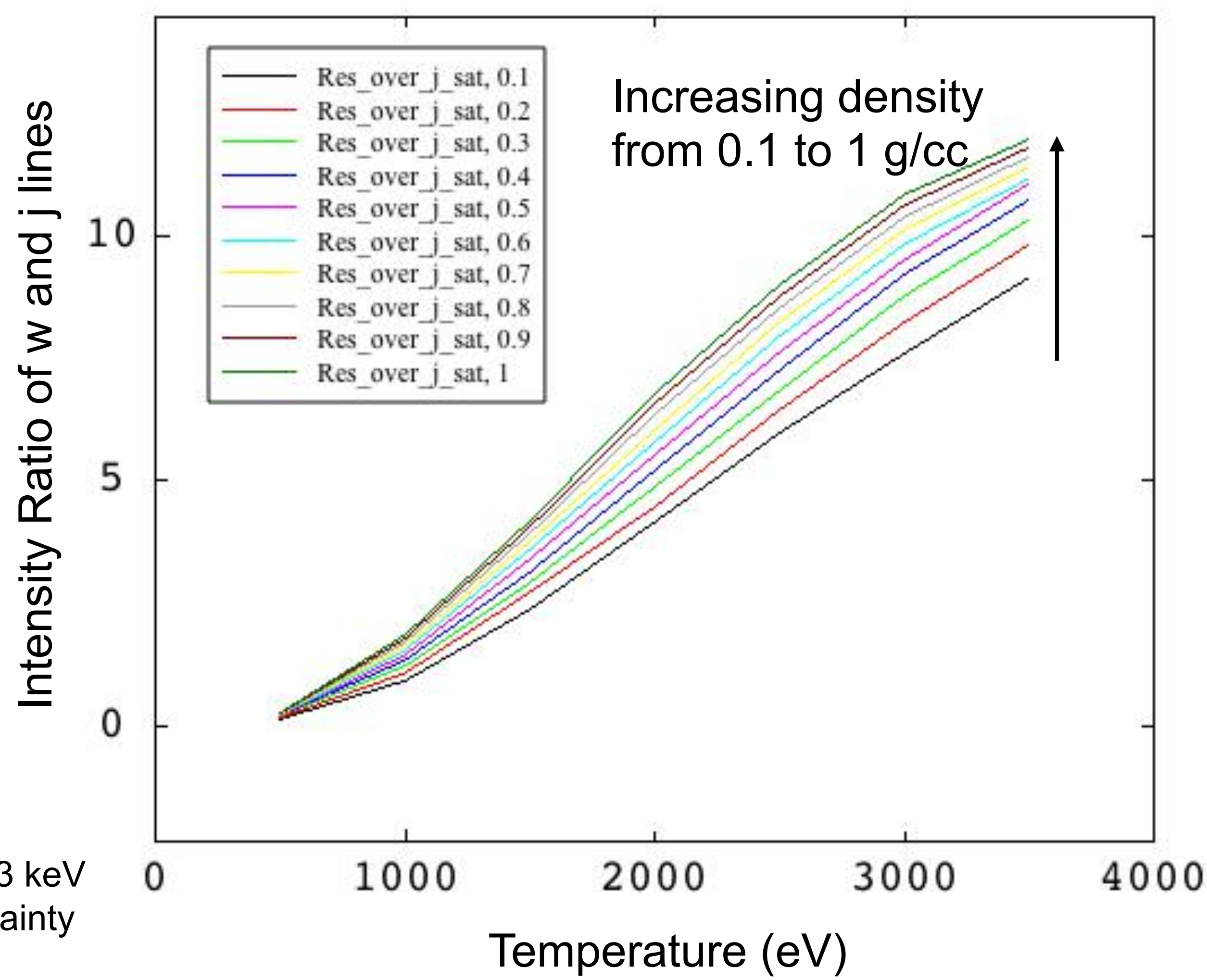


10% uncertainty in line ratio measurement yields 0.4 g/cc +/- 0.1 g/cc (25% uncertainty)



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.