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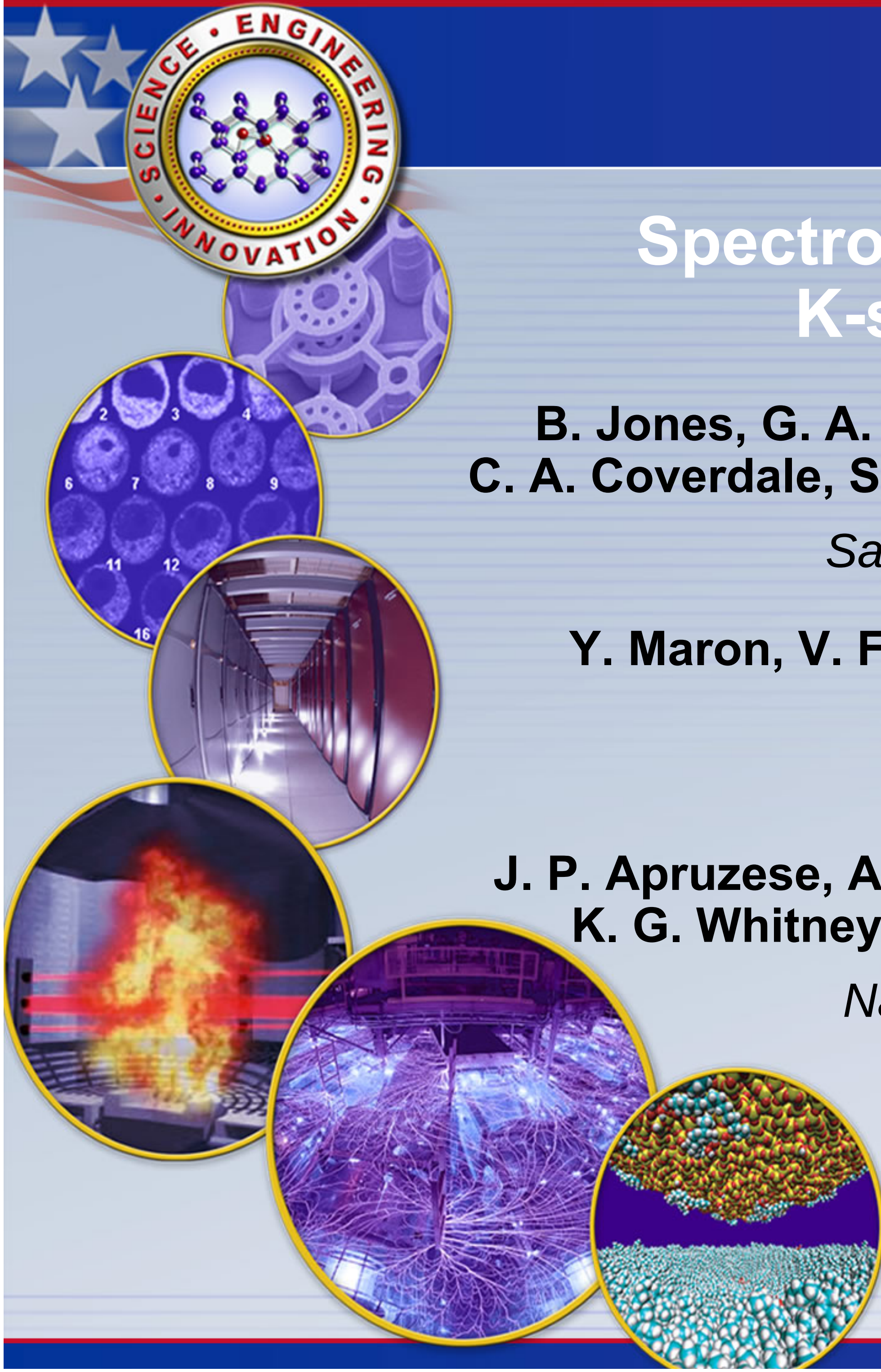

Spectroscopic study of z-pinch K-shell x-ray sources

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APS DPP 2009
November 5, 2009

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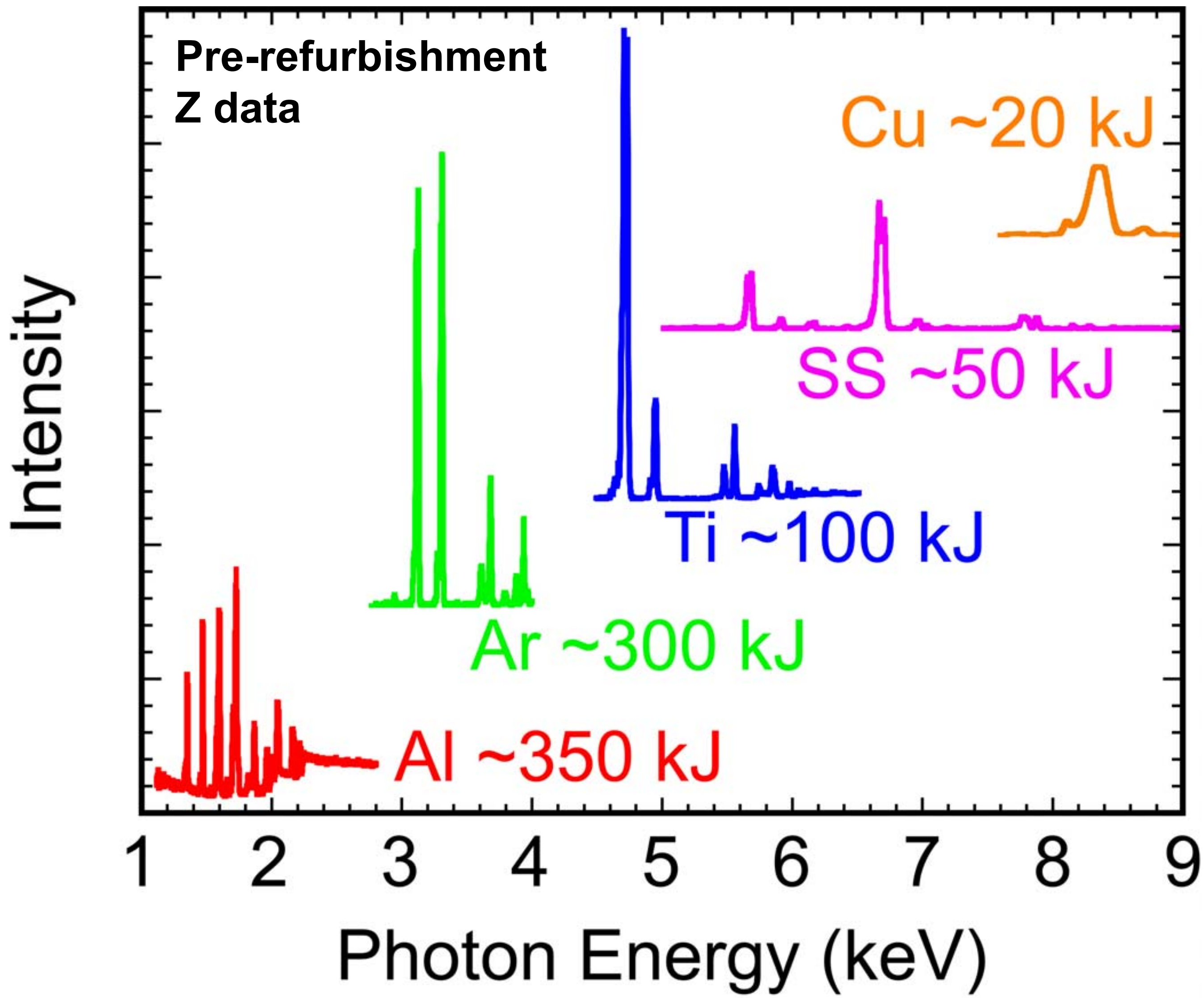
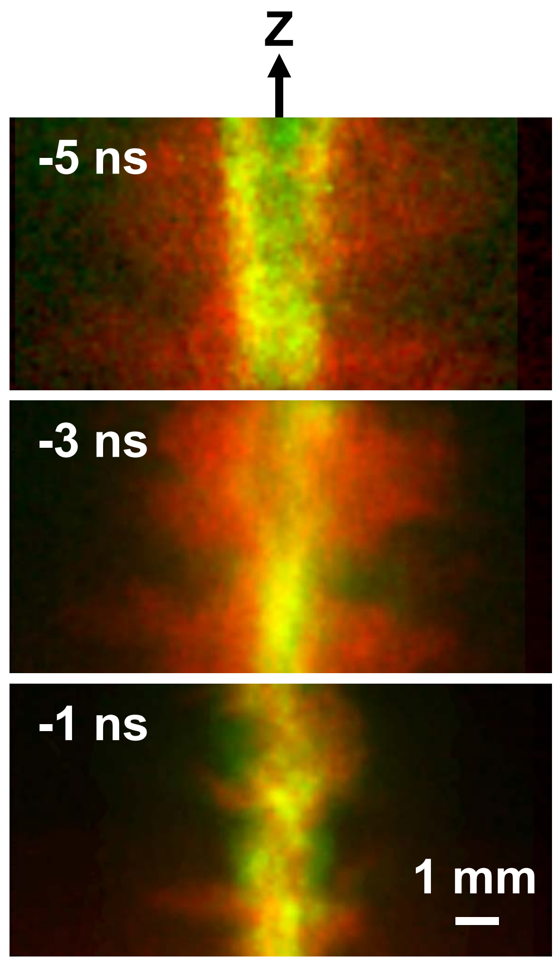
Outline

- The Z machine provides intense 1-10 keV K-shell x-ray sources
- These provide a natural opportunity to understand z-pinch implosions and plasma conditions via x-ray spectroscopy
- Time- and space-resolved spectra encode information about the plasma conditions and velocities
- Doppler effects influence the line shapes and can be used to infer plasma implosion velocities

Z-pinch implosions provide extremely intense 1-10 keV x-ray sources





Pulse widths 2-25 ns,
Rise times 2-20 ns
±30% absolute errors

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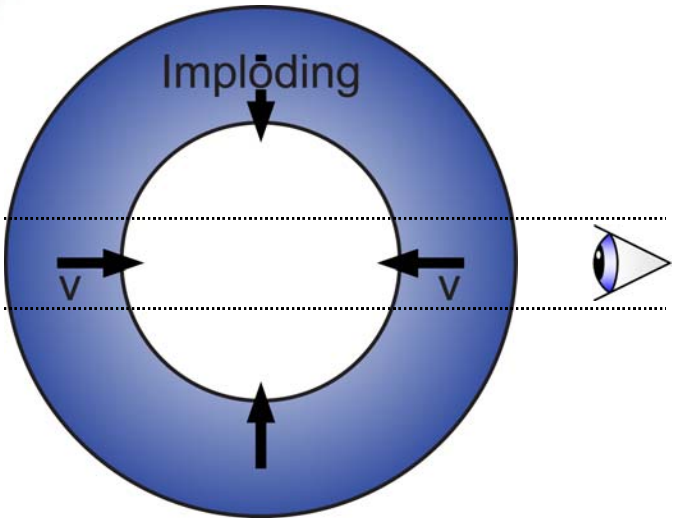
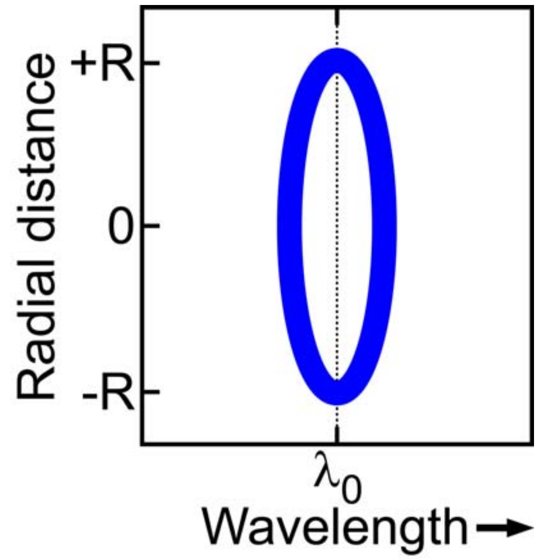
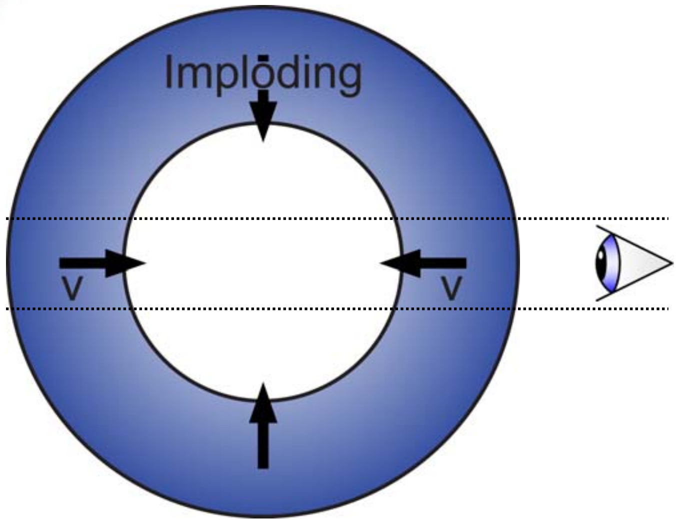
Doppler shift is observed spectroscopically in a moving plasma shell

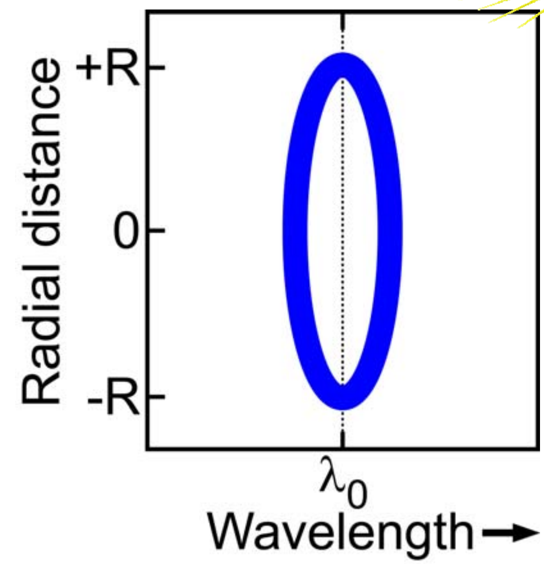


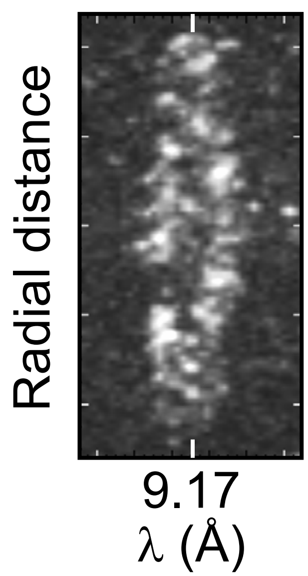


- **Information about the plasma is encoded in the spatial and spectral profiles of the line emission**
- **If emission is optically thin, then a 1D radially resolved spectrometer will see an oval-shaped line profile**

Doppler shift is observed spectroscopically in a moving plasma shell

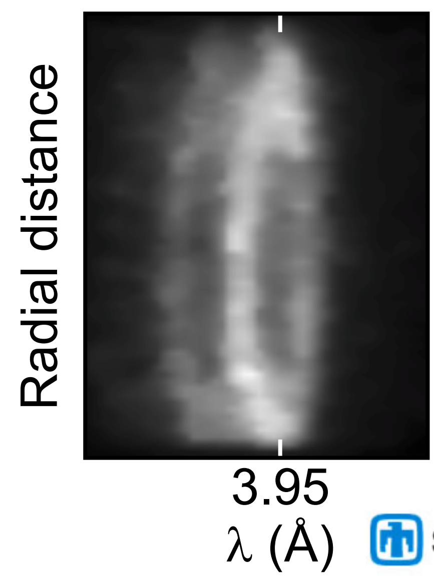






Mg He-α

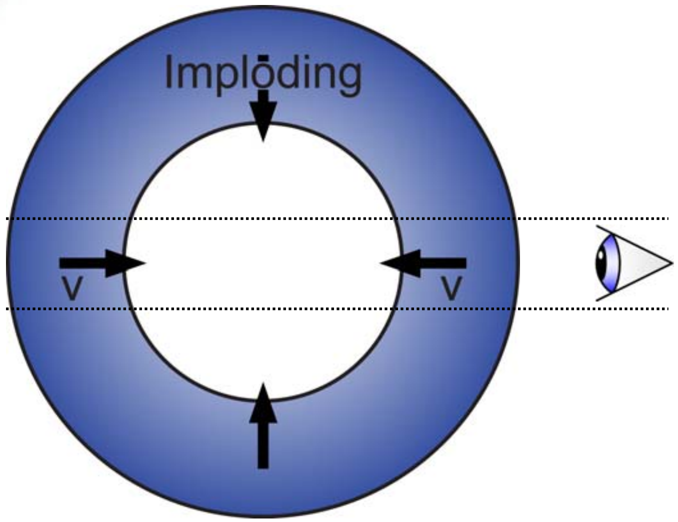
Ø40 mm
wire array
95% Al
5% Mg

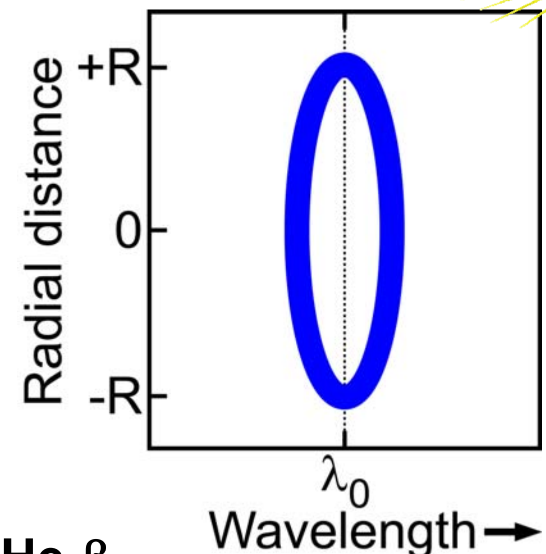


Ar He-α

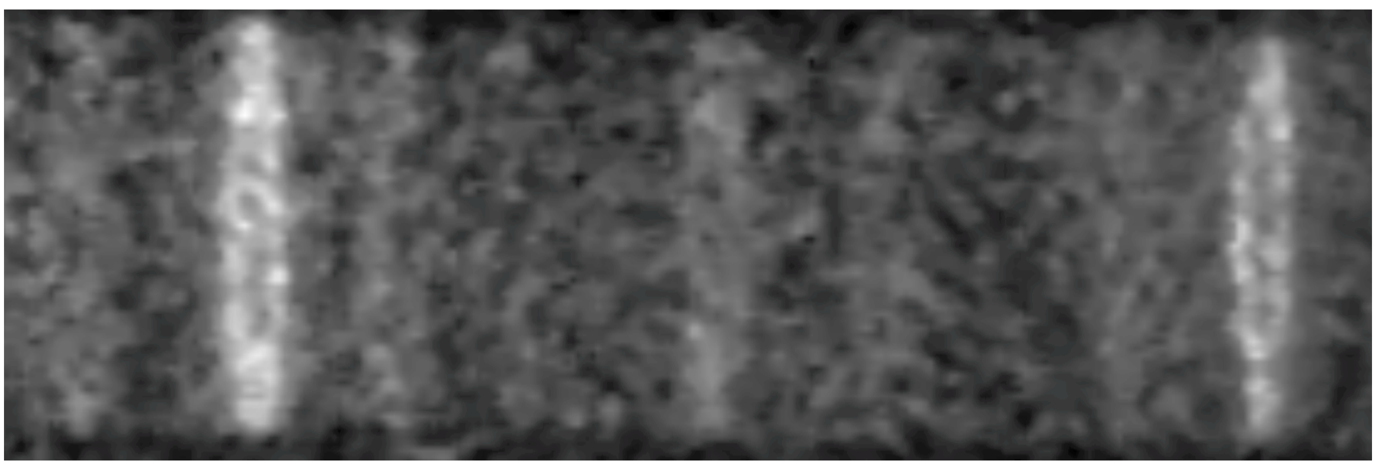
Ø80 mm
gas puff
99.5% D_2
0.25% Ar
0.25% Freon

Doppler shift is observed spectroscopically in a moving plasma shell

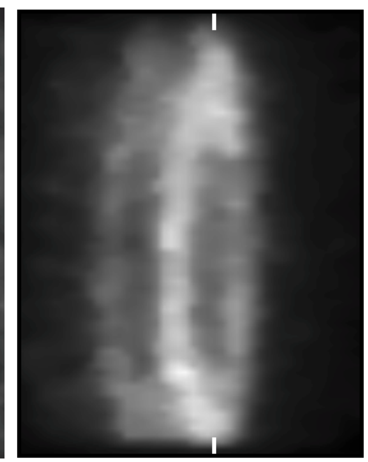




Ar He-β **Cl He-β**



Ar Ly-α Wavelength →



3.95
λ (Å)

Ar He-α

Ø80 mm
gas puff
99.5% D_2
0.25% Ar
0.25% Freon

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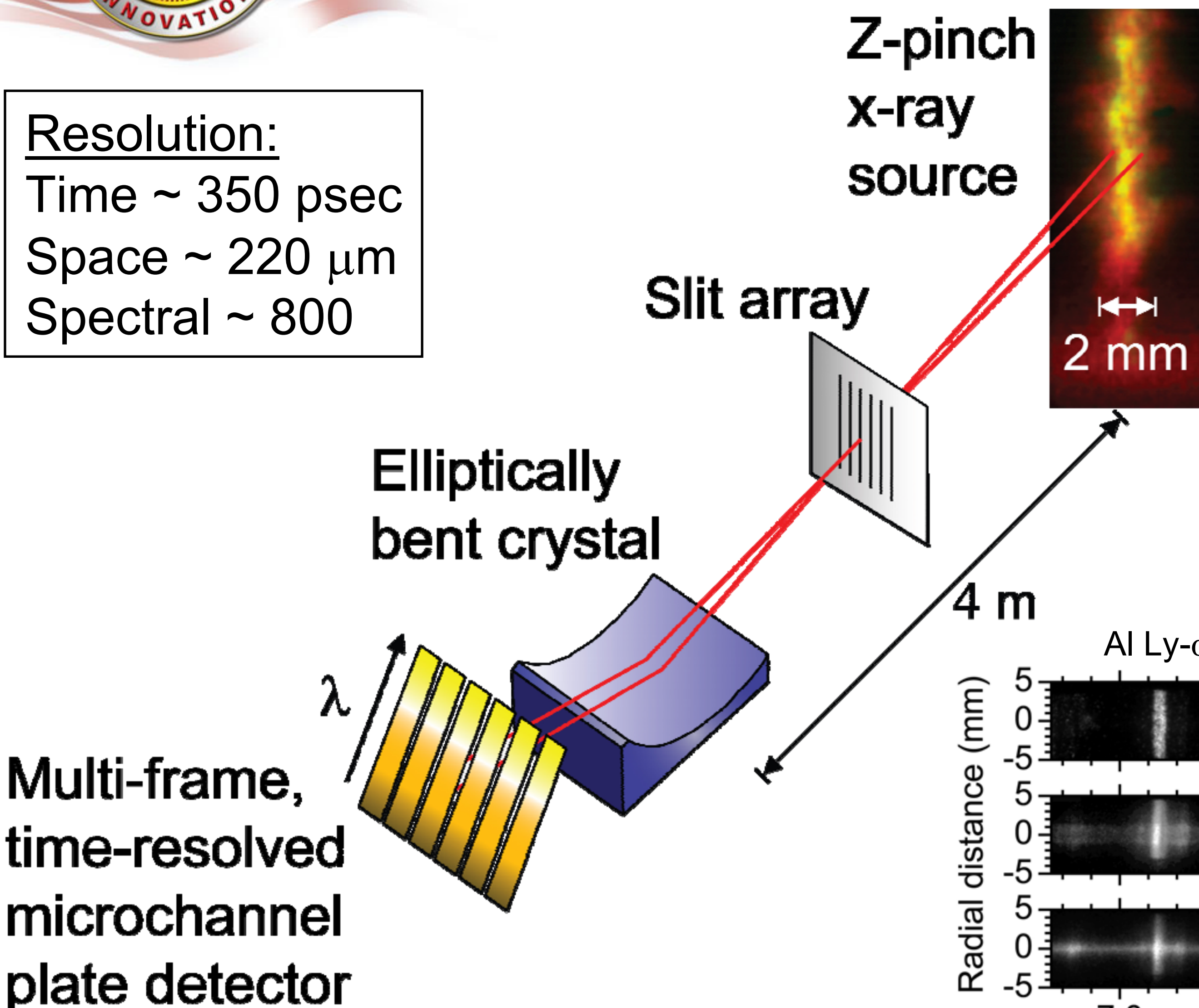
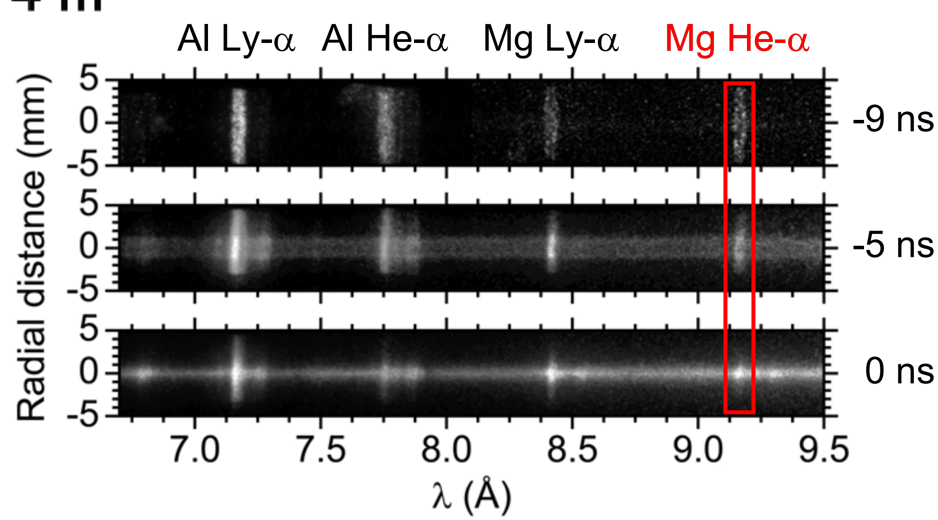
Time- and space-resolved crystal spectrometers provide a powerful diagnostic capability on Z

<u>Resolution:</u>
Time ~ 350 psec
Space ~ 220 μm
Spectral ~ 800

- **Slits provide 1D (radial) spatial resolution for multiple frames**
- **Elliptically bent mica crystal provides dispersion**
- **MCP gated detector**

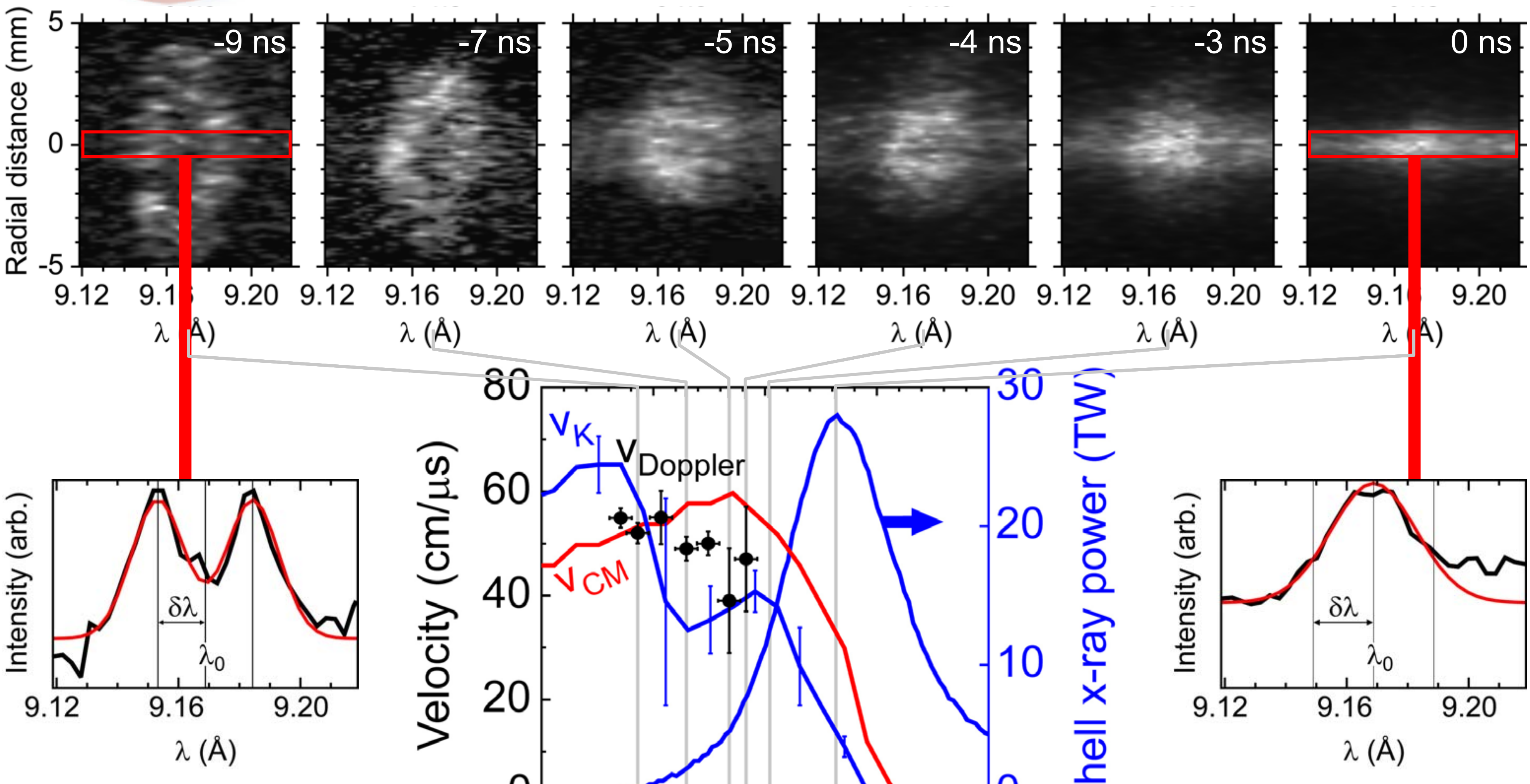




- J.E. Bailey *et al.*, PRL **92**, 085002 (2004).

Doppler splitting vanishes at the start of the main x-ray rise—thermalization of kinetic energy

Z1520, Ø40 on 20 mm nested Al 5056 wire array, 1.5 mg/cm, Mg He-α



$$v = \frac{c\,\delta\lambda}{\lambda_0 \cos\theta}$$

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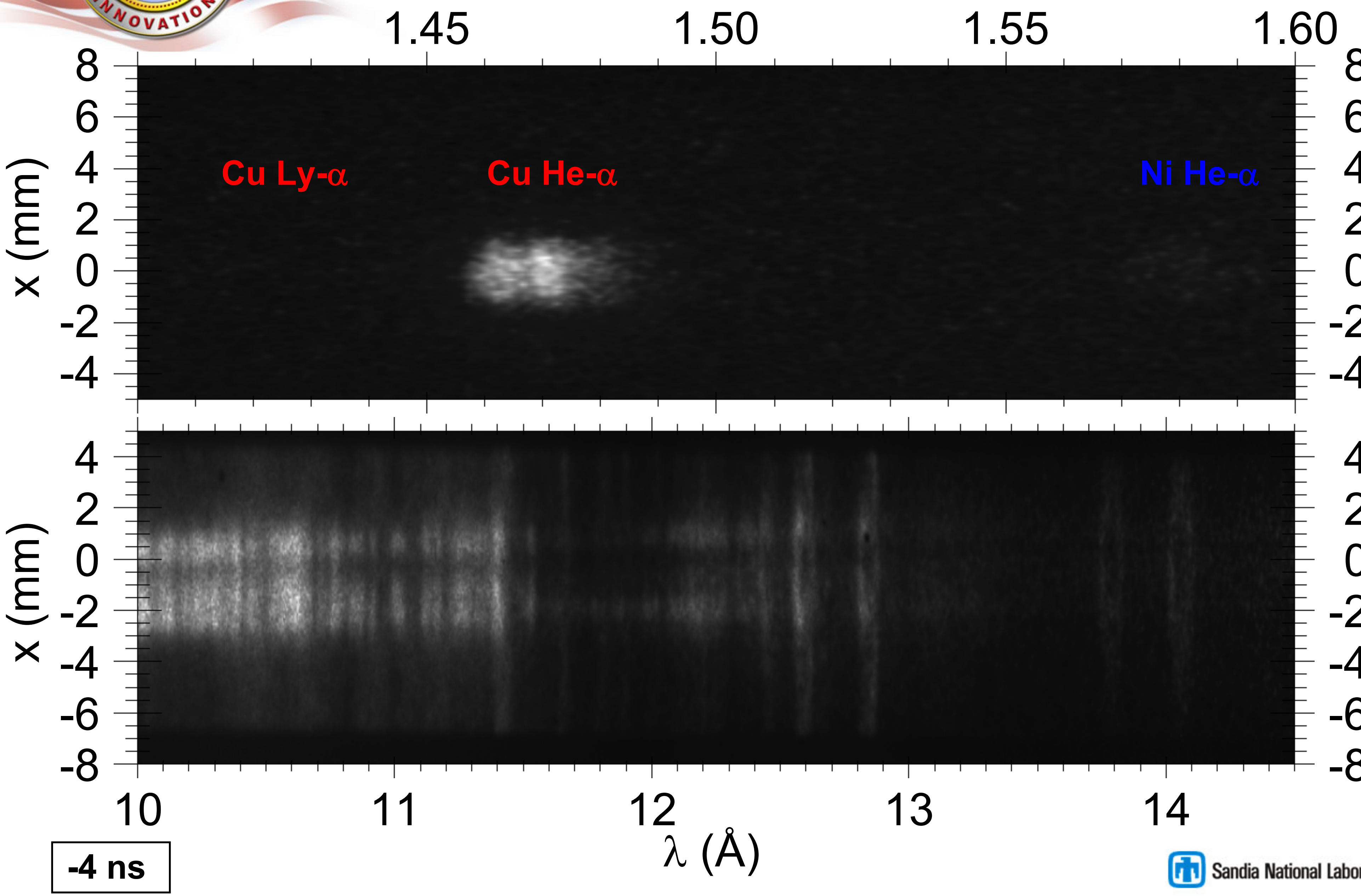
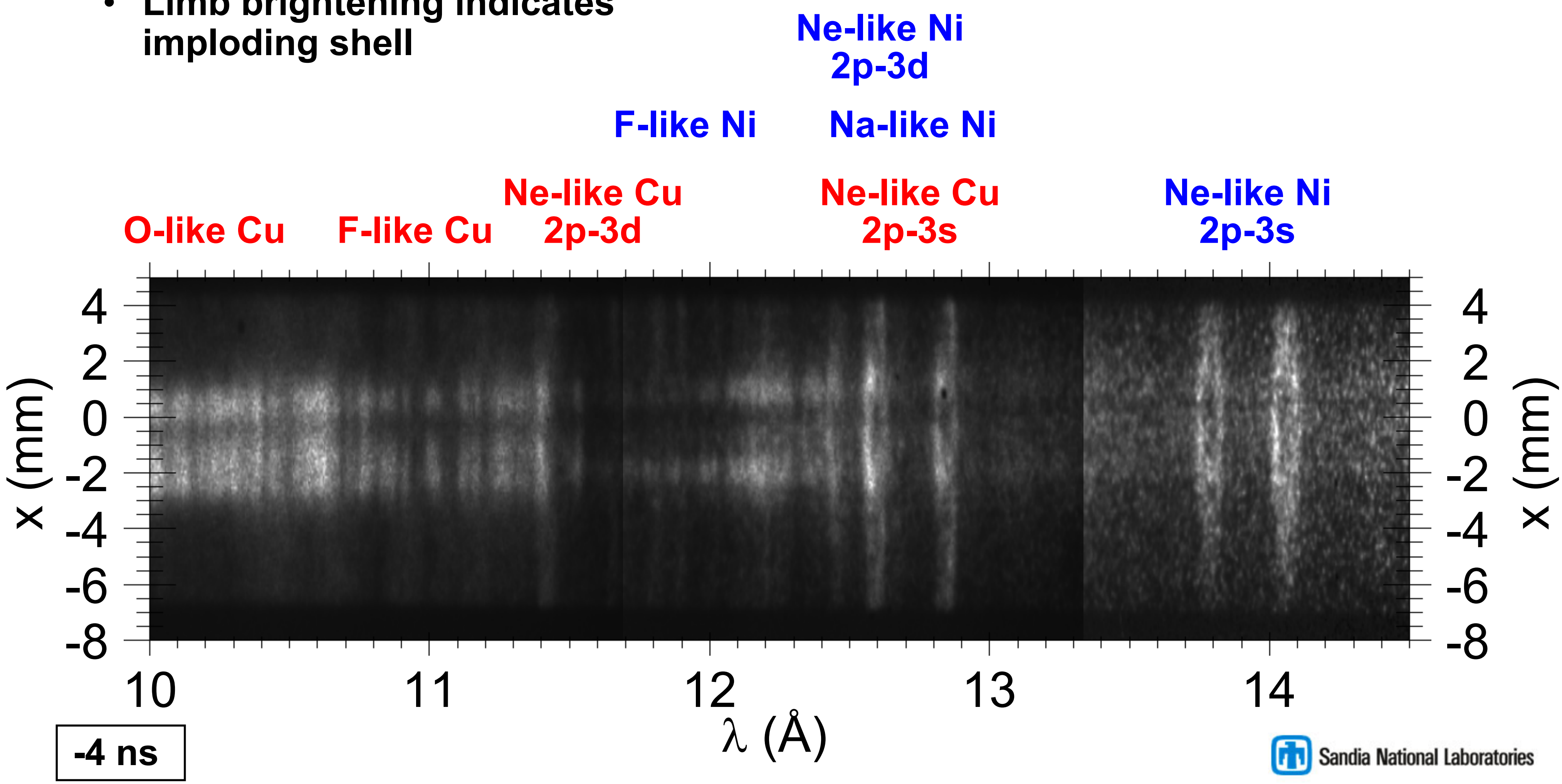
K-shell emission from narrow column, with L-shell emission from larger radius on Z

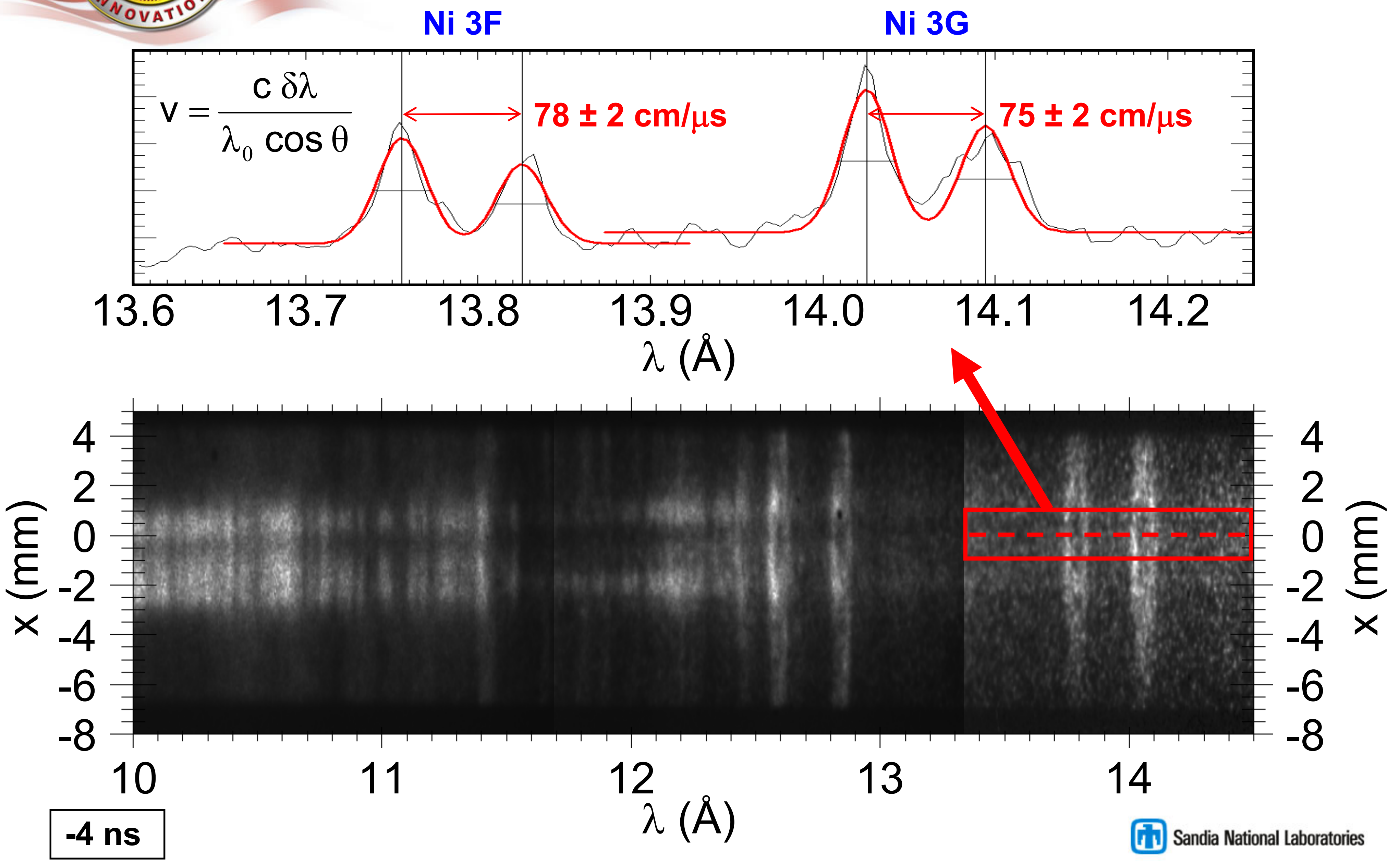


L-shell emission is observable prior to stagnation, useful for studying imploding plasma

- ~4% Ni dopant in nested Cu wire array; Cu and Ni L-shell emission is seen
- L-shell lines show Doppler splitting at the foot of the x-ray pulse
- Limb brightening indicates imploding shell



Average velocity of the emitting plasma is obtained from Doppler splitting



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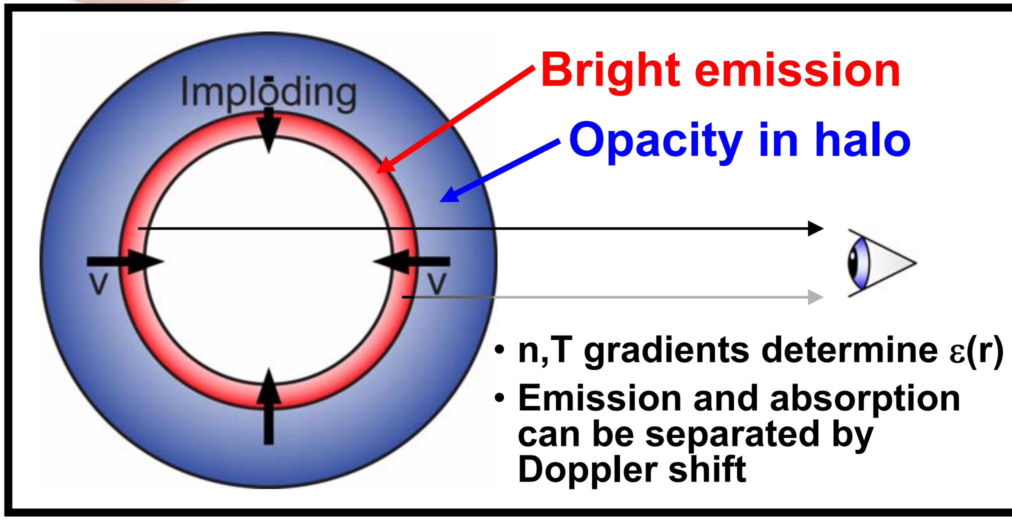
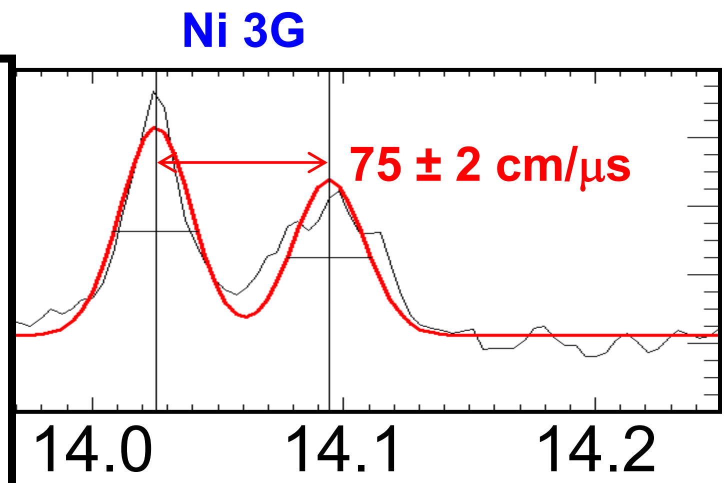
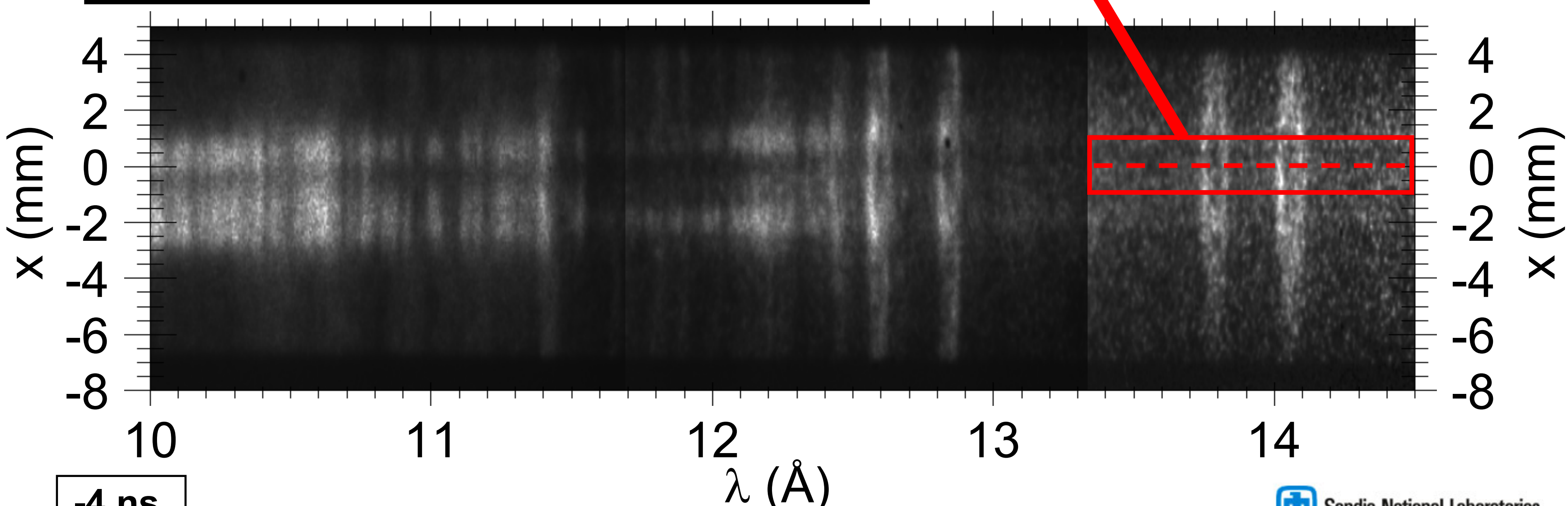
Plasma gradients can lead to asymmetric spectral line profiles



- n,T gradients determine ε(r)
- Emission and absorption can be separated by Doppler shift





-4 ns

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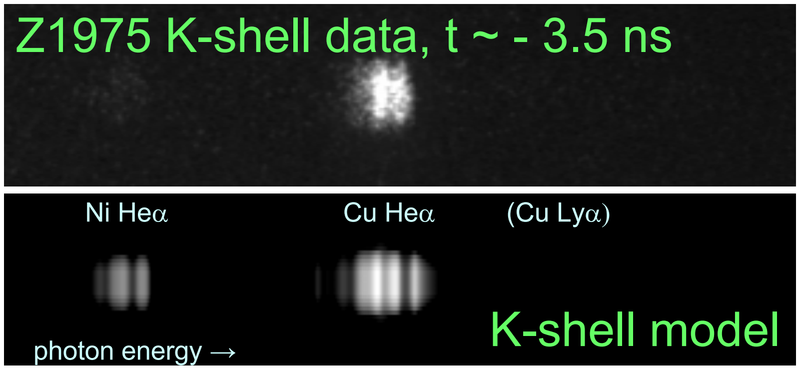
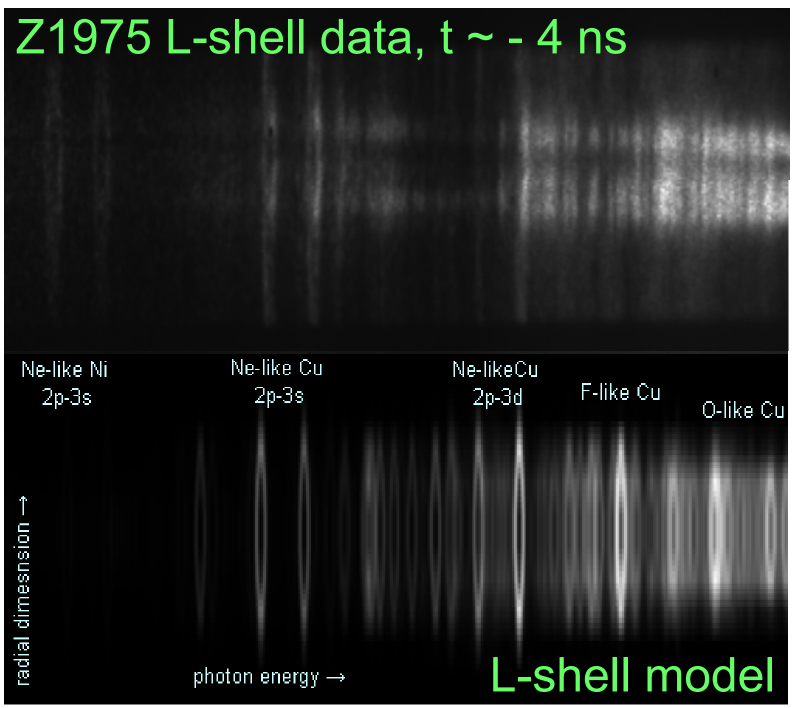
Time-gated, radially resolved K- and L-shell emission yield a wealth of information

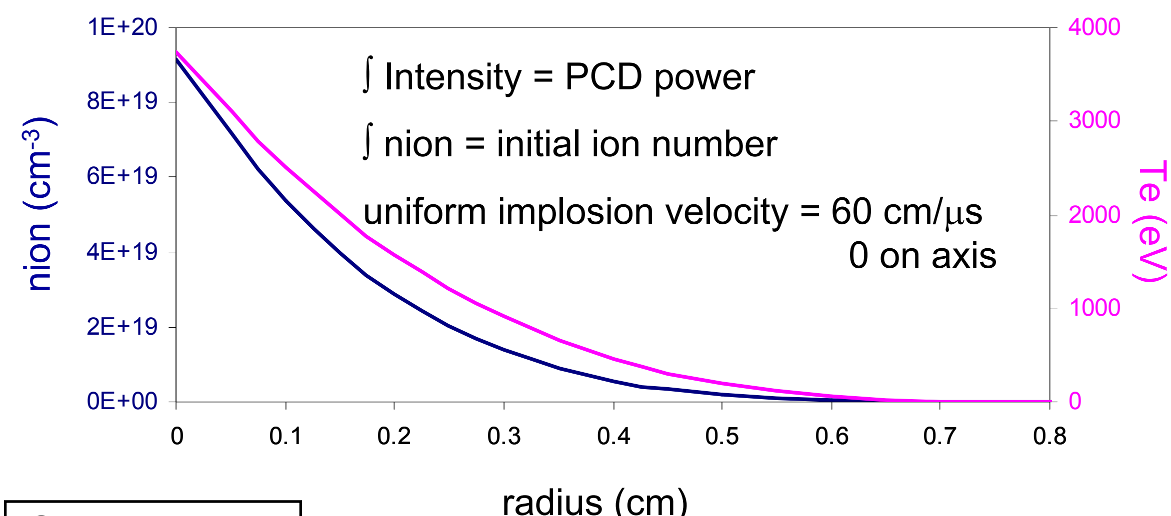




-Obtain core radius, temperature, and density from K-shell emission and PCD signals (c.f. NRL)

-Obtain implosion velocity and gradient scale lengths from L-shell emission and mass conservation

-Future analysis will add self-consistent radiative transfer to test non-monotonic T & ρ profiles using asymmetries in lineshapes



S. B. Hansen

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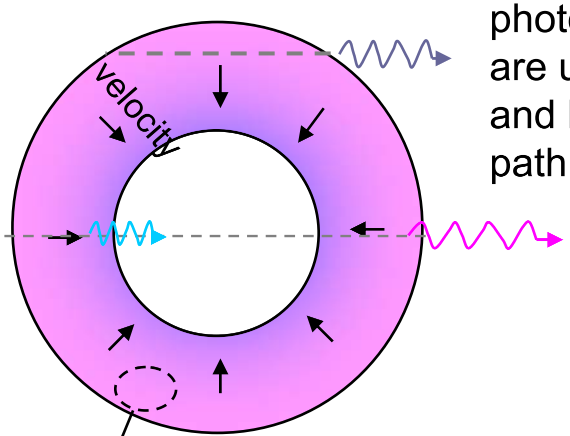
Opacity and gradients can lead to asymmetric line profiles

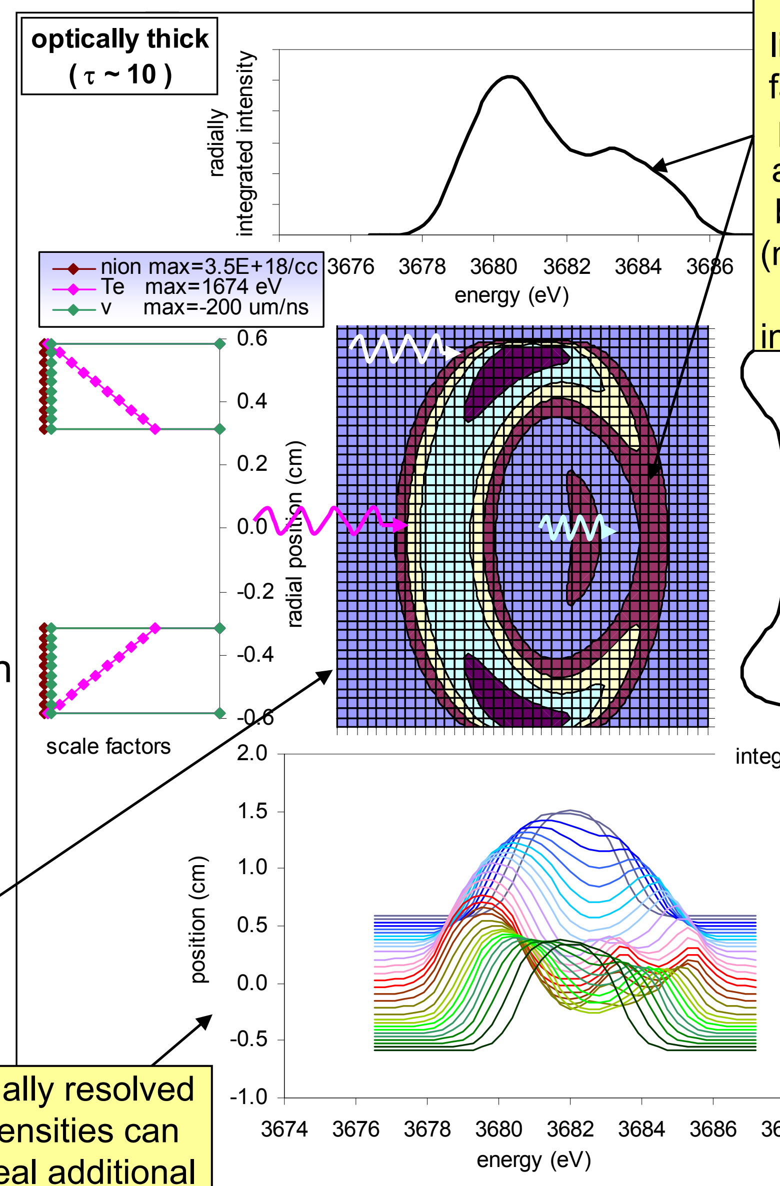
Example:
- imploding plasma shell
- optically thick Argon Heβ



photons from shell edge are unshifted ($v_{||} = 0$) and have the shortest path length

photons from shell center are maximally shifted ($v_{||} = v$) and have the longest path length

plasma conditions:
nion = ion density
Te = electron temperature



Blue-shifted lines from the far side of the plasma shell are absorbed by the cooler (more opaque) co-moving interior plasma

lineout of radial intensity shows limb brightening

contour plot gives simulated image of radially resolved emission including Doppler shifts and transport

radially resolved intensities can reveal additional information

- **S. B. Hansen, poster CP8.45, DPP09**

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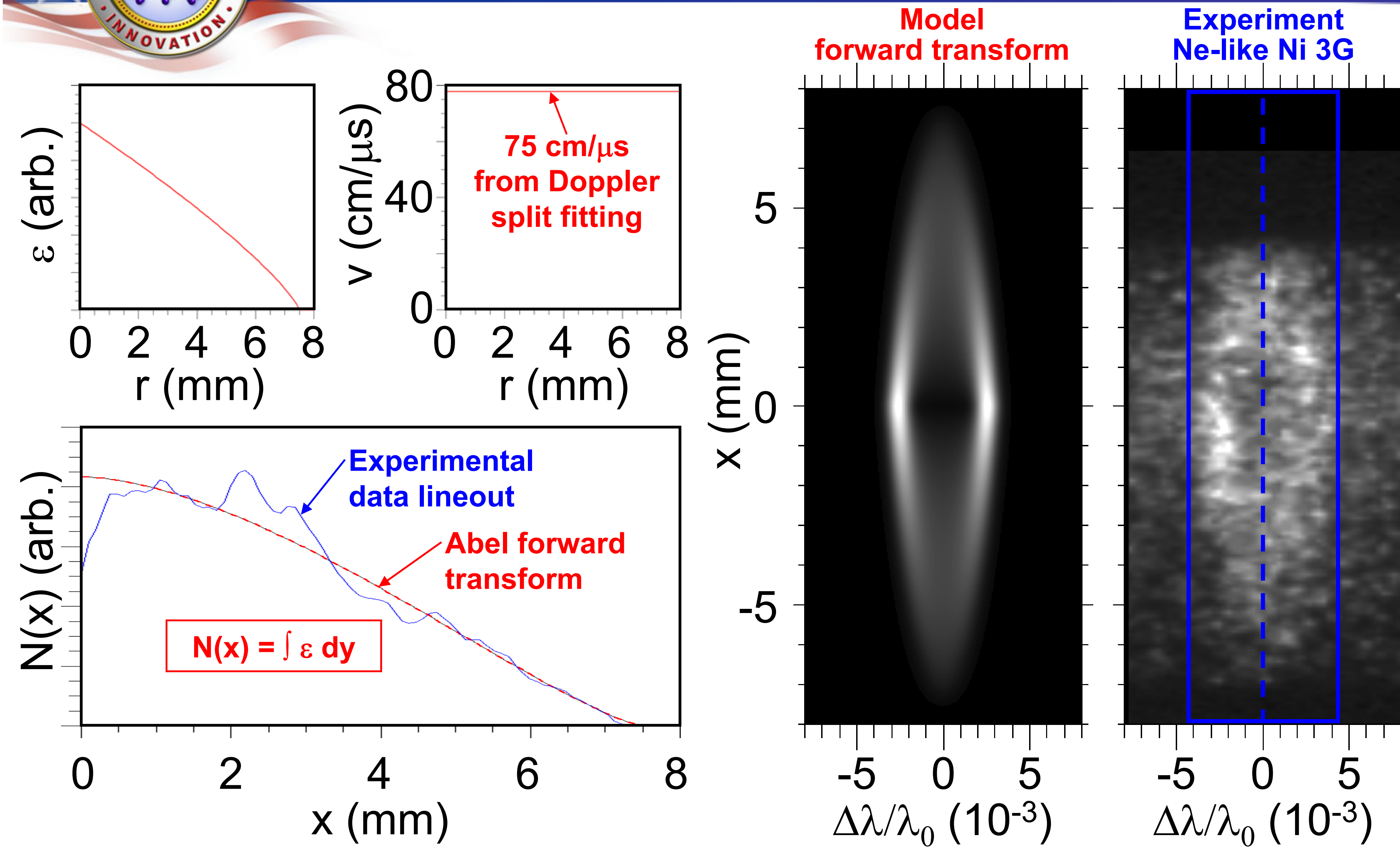
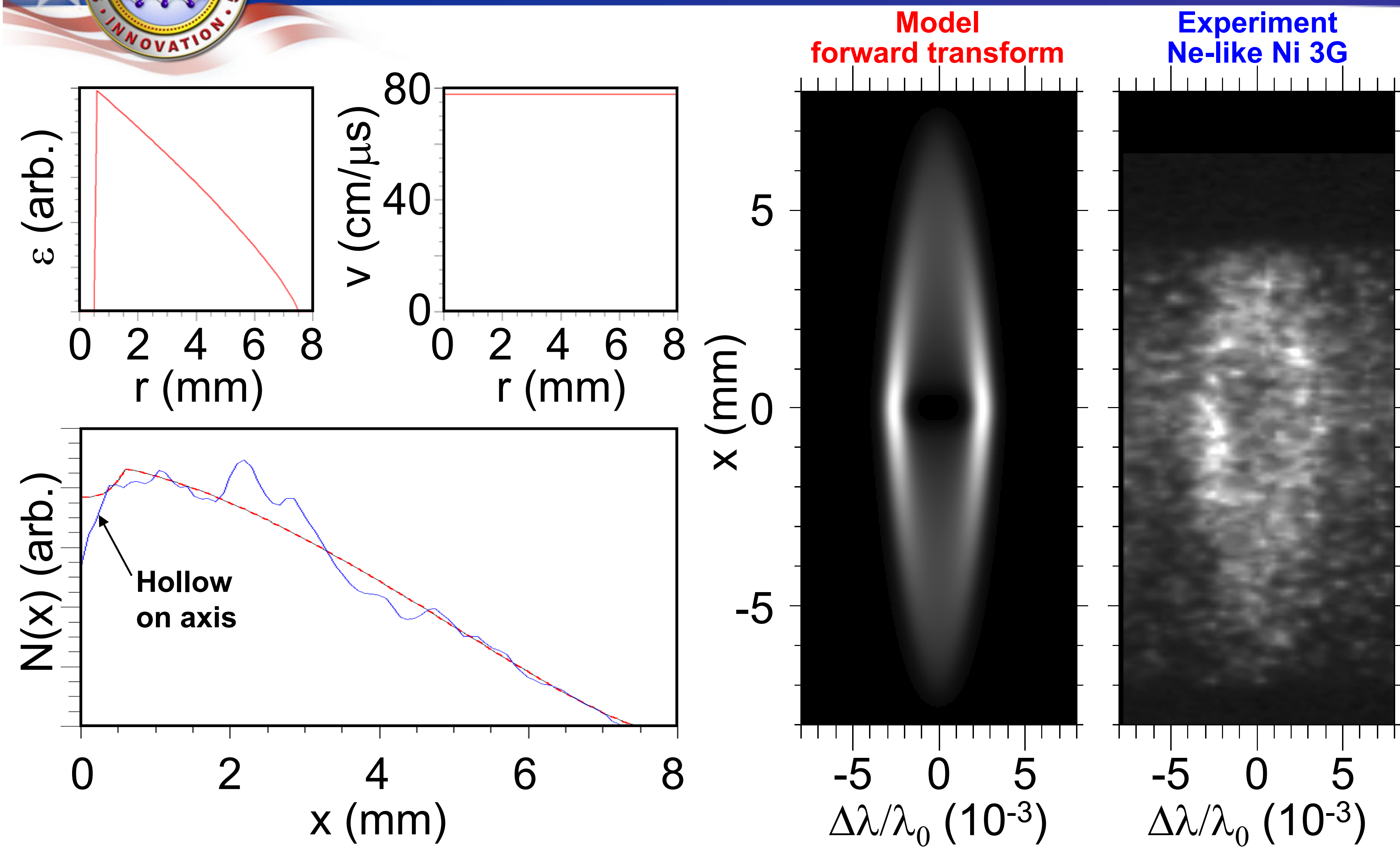
Plasma ε,v profiles are encoded in spectral and 1D radially resolved line profiles



- **Smoothing for 400 μm spatial, λ/Δλ=1000 spectral resolution**

Plasma ε,v profiles are encoded in spectral and 1D radially resolved line profiles



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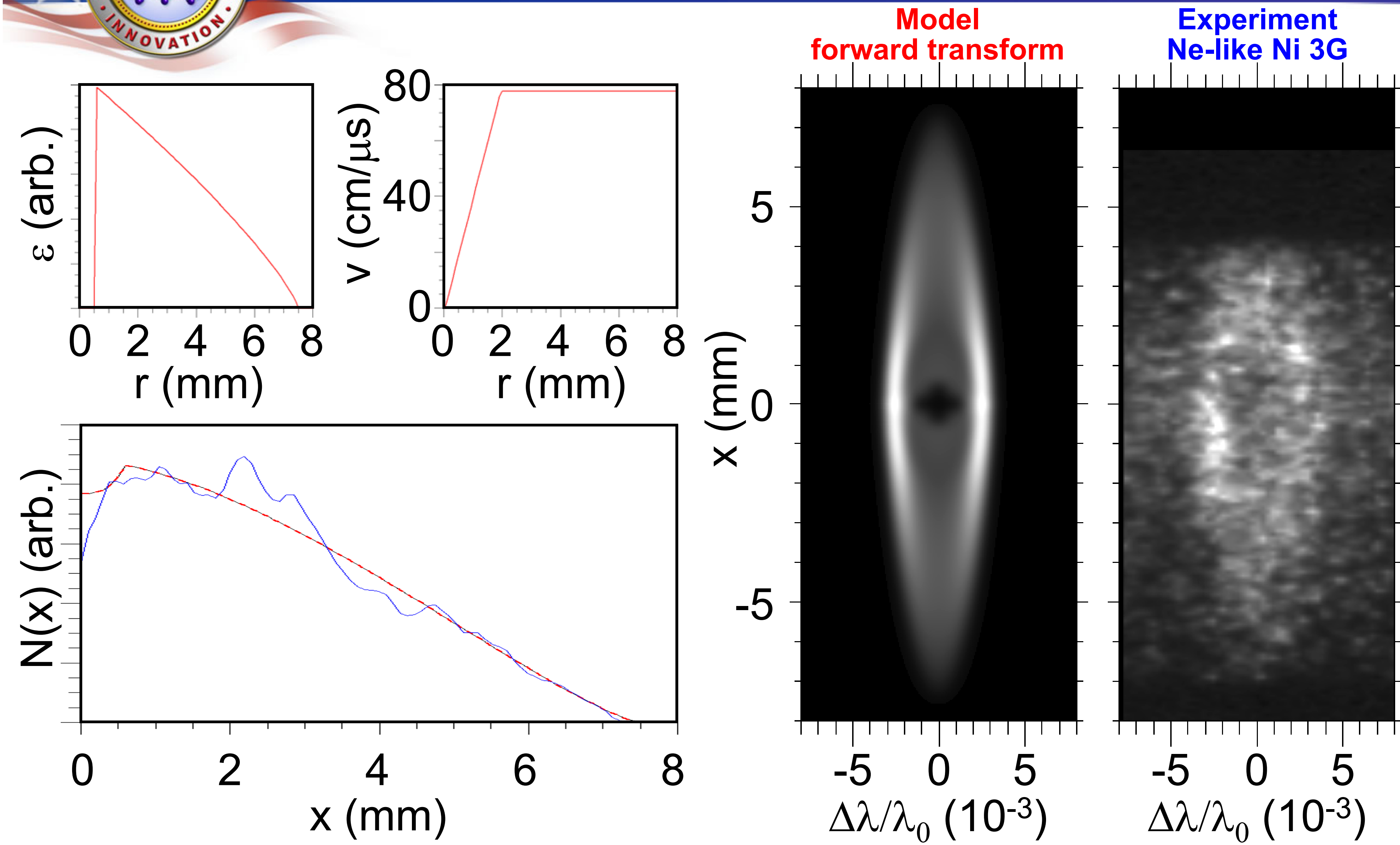

- **Smoothing for 400 μm spatial, $\lambda/\Delta\lambda$=1000 spectral resolution**

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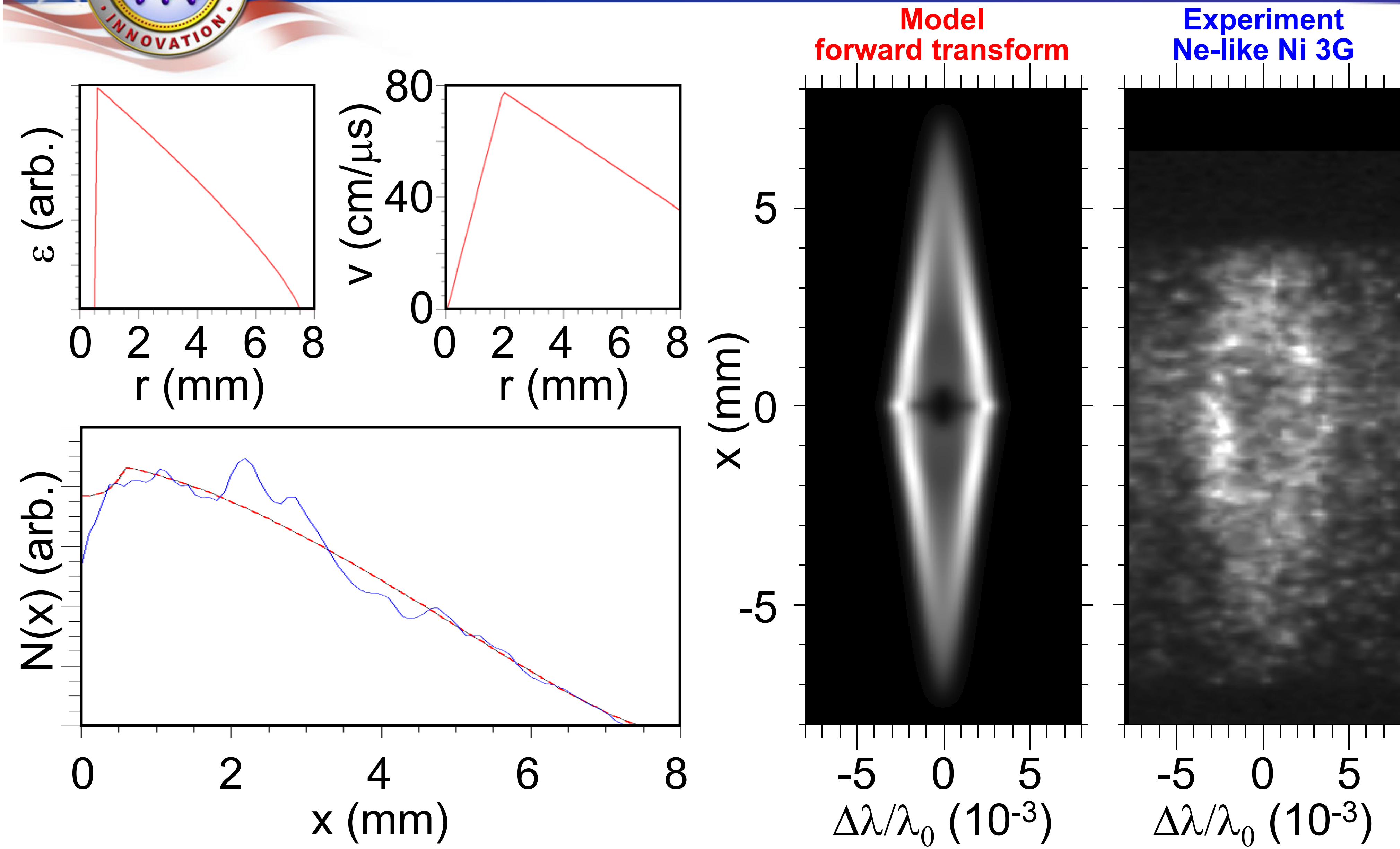
Plasma ε,v profiles are encoded in spectral and 1D radially resolved line profiles



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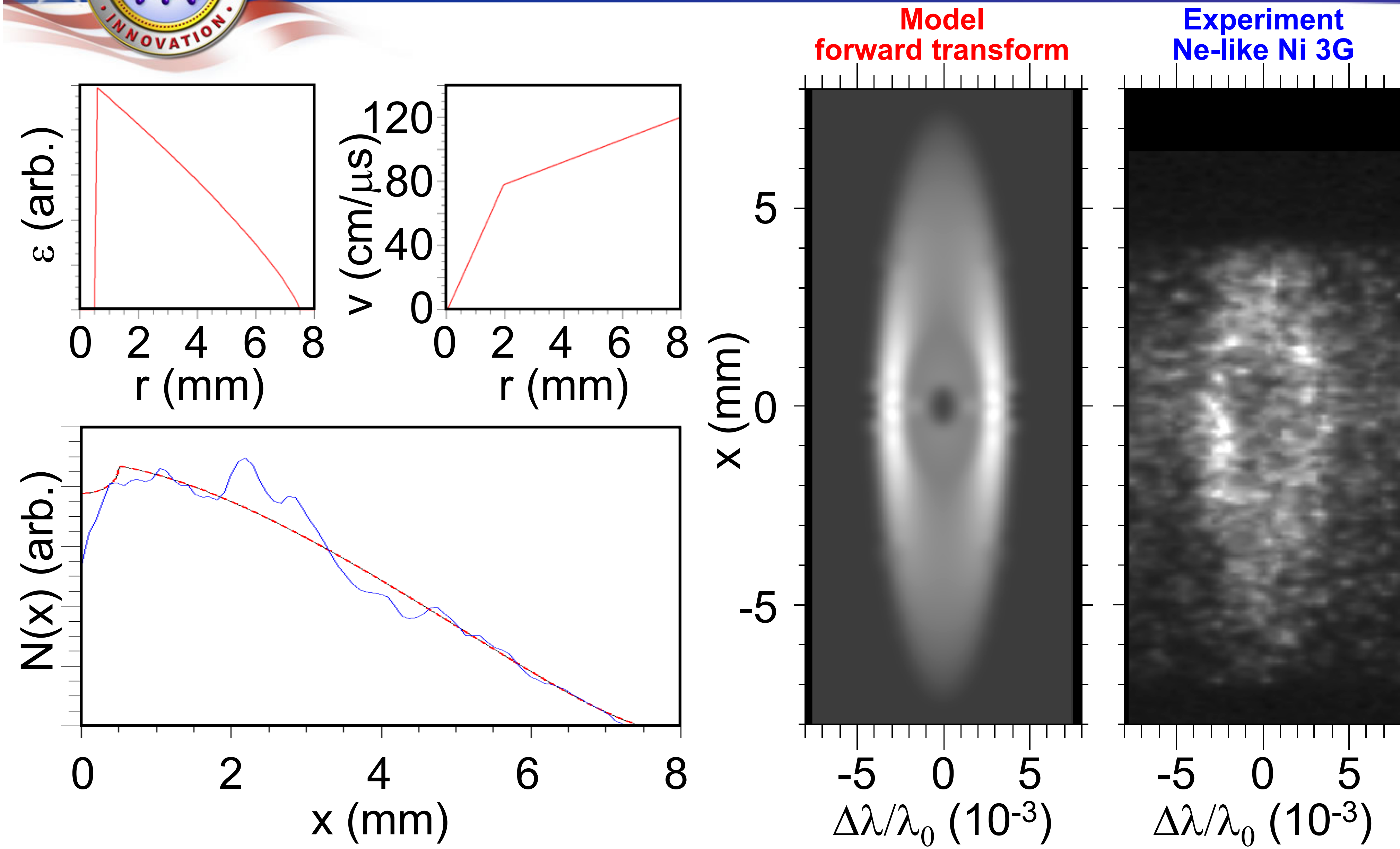

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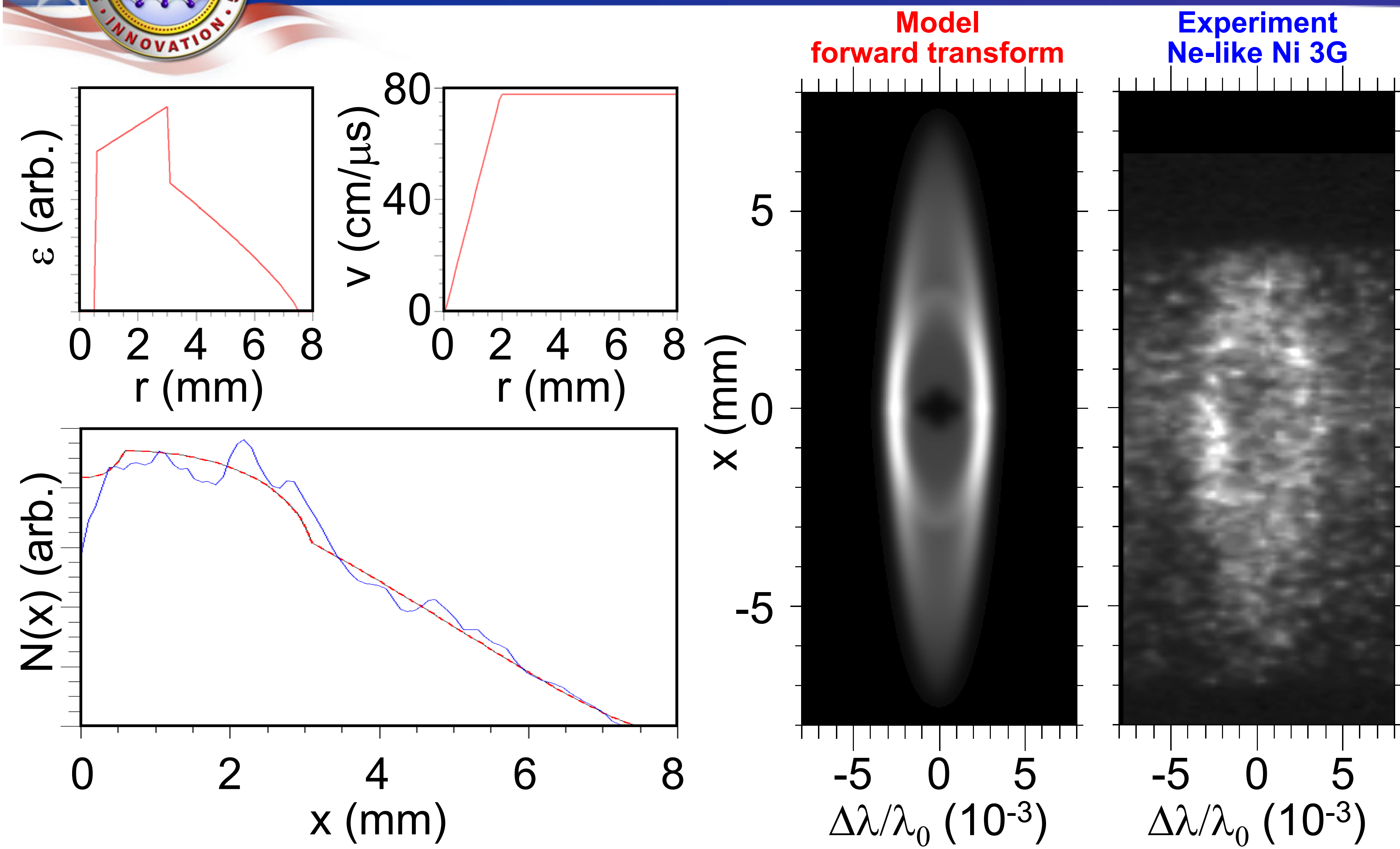
Plasma ε,v profiles are encoded in spectral and 1D radially resolved line profiles



- **Smoothing for 400 μm spatial, λ/Δλ=1000 spectral resolution**

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Summary

- Z provides intense x-ray sources (1-10 keV photons, of order 100 kJ yields)
- K- and L-shell spectroscopy can provide information on plasma n, T, v
  - Line shapes are sensitive to Doppler effects and gradients
- Ongoing analysis challenges include:
  - Inversion method to obtain unique ε, v profiles from 1D radially-resolved time-gated spectra with line shapes dominated by Doppler effects
  - Line ratios to constrain n, T profiles
  - Atomic modeling with transport to link line asymmetries and spatial structure to plasma profiles
  - Post-processing of MHD models to simulate 1D radially-resolved spectra and compare to measurements