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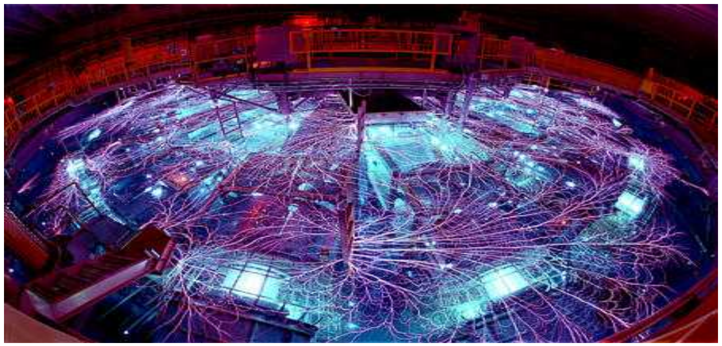

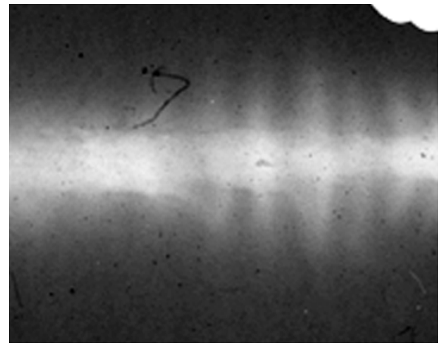

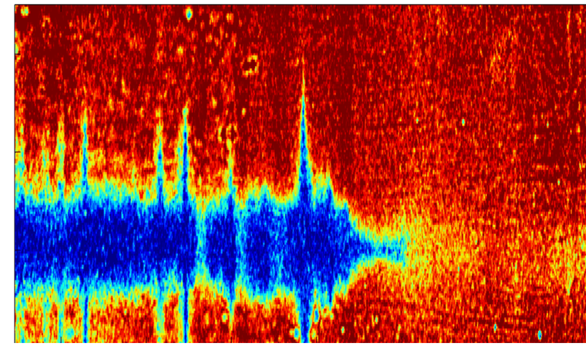

Investigation of Exploding Wire Plasmas Using High Resolution Point Projection X-ray Absorption Spectroscopy

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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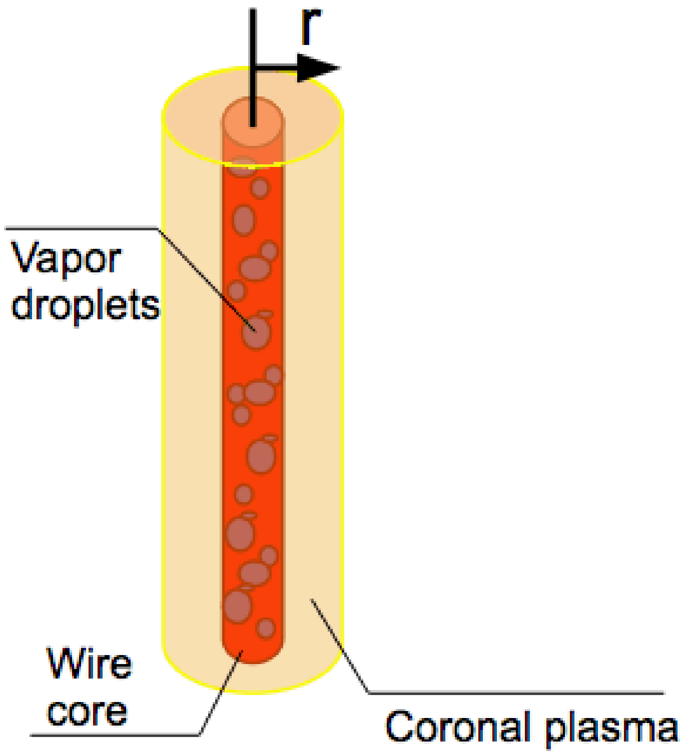
Outline

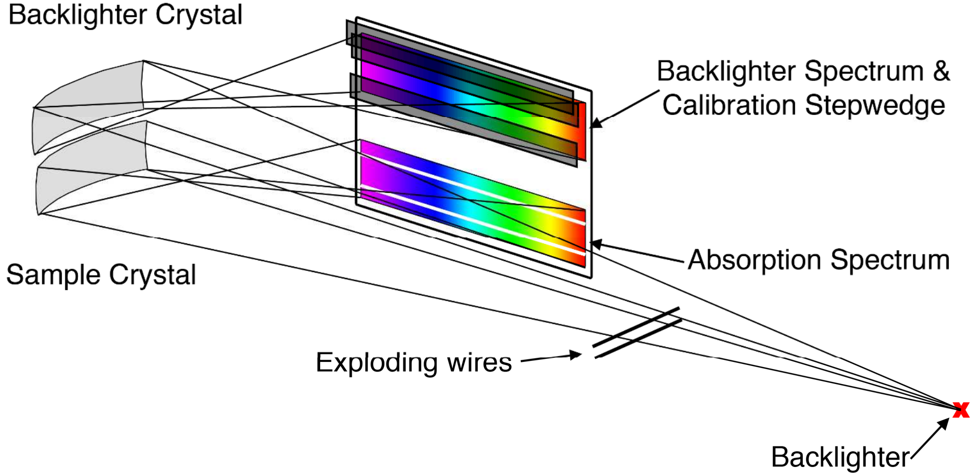
- Introduction
- Experimental Setup
- Single Exploding Wires
- Two Parallel Wires
- Data Analysis
- Results
- Conclusions

Absorption Spectroscopy Can Probe Previously Unreachable Plasmas

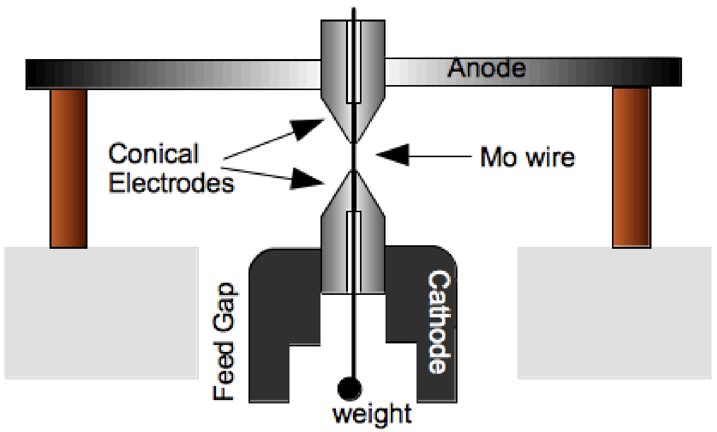
- Corona, precursor optically thick to visible/UV radiation, thin to x-rays
- Penetrate wire cores
- Extend accessible parameter space with existing techniques/equipment
- Measure plasma density and temperature vs. space & time
  - Ionization Processes
  - Energy Transport
  - Material Properties



Experimental Setup



Hybrid X-Pinch[2,*]



- Backlighter crystal & step wedge allows in-situ calibration
- Spherical crystals give high luminosity, resolution[1]

$$\delta x = 20\mu m \qquad \frac{\lambda}{\Delta\lambda} \cong 5000$$

- Easier to load
- Reduction in multiple pinches
- Reduction in e^- beam radiation
- Spot size and duration at least as good as traditional x-pinch

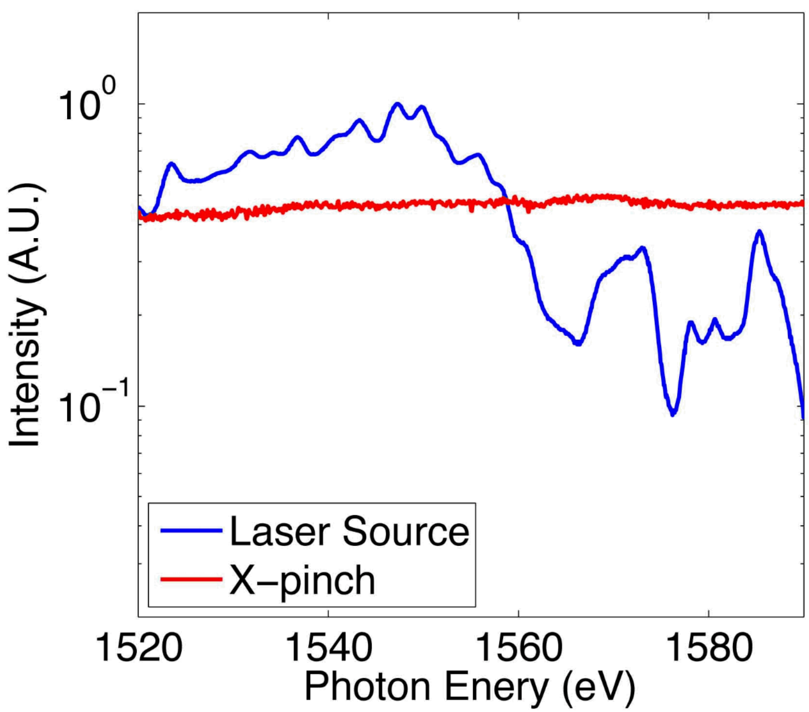
*Shelkovenko et al., Wed. 2:00 pm, PP9.00110

[1] Knapp et al., Rev. Sci. Instrum., **82**, 063501 (2011)

[2] Shelkovenko et al., Phys. Plasmas **17**, 112707 (2010)

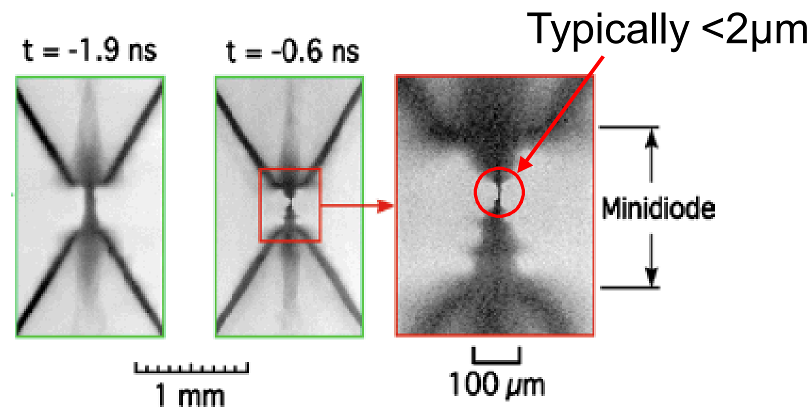
X-pinch is a Superior Backlighter

Comparison of laser-produced to x-pinch x-ray source

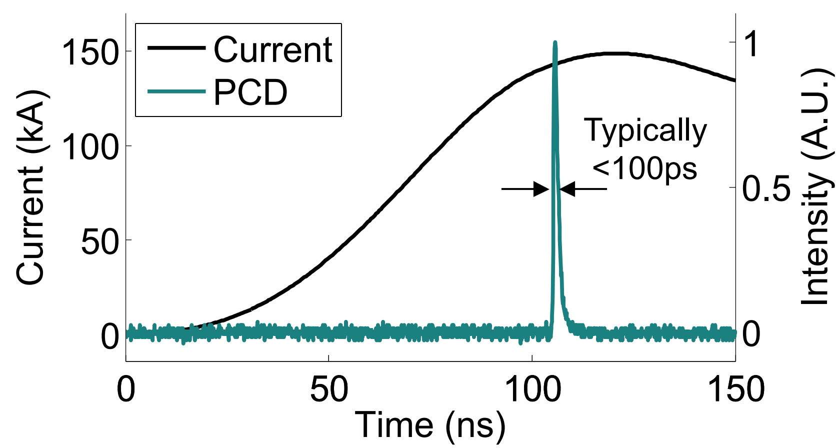


- Extremely Smooth Continuum Spectrum
- Helps to alleviate some errors in analysis

Backlighter Source Size

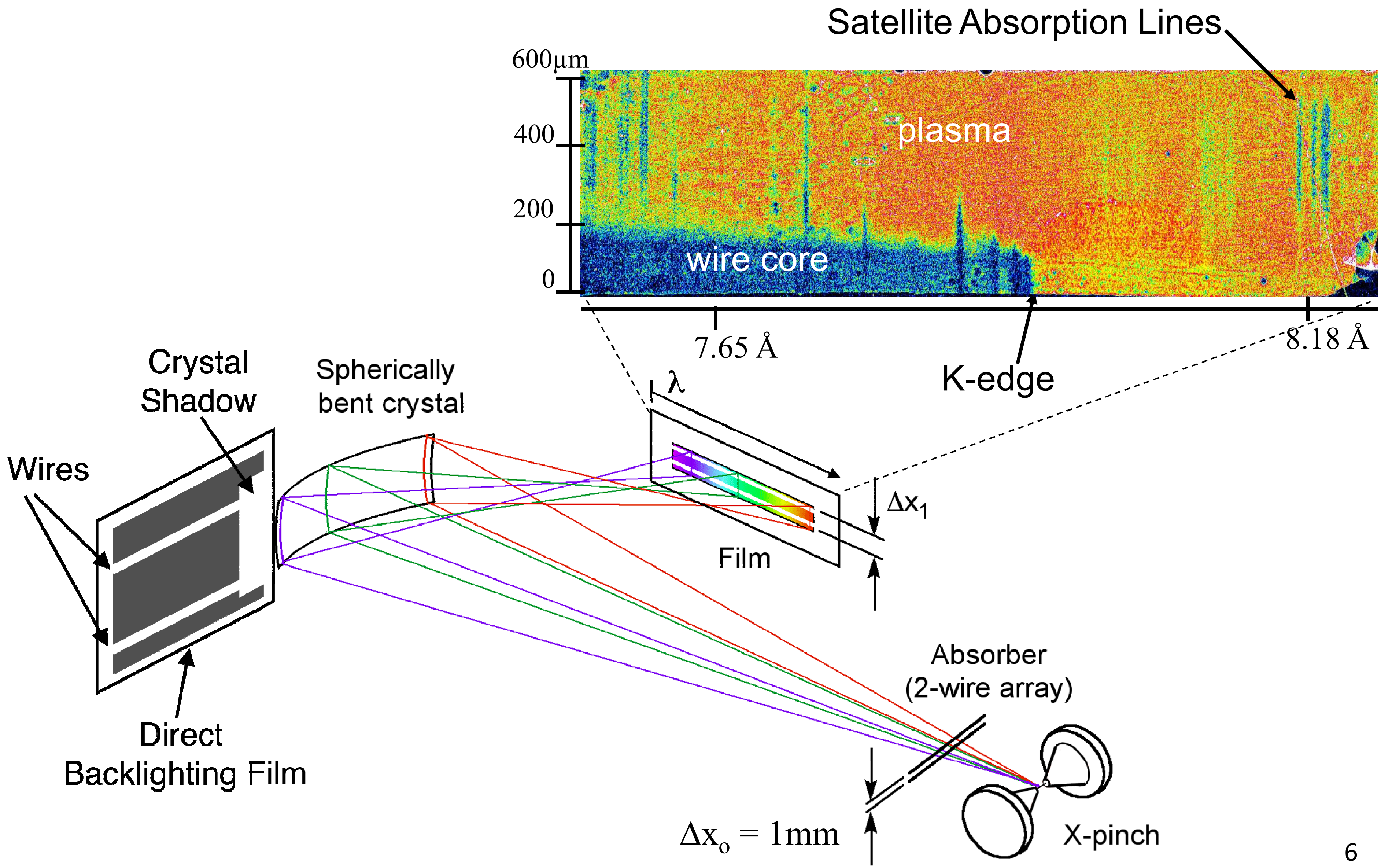


Backlighter Duration



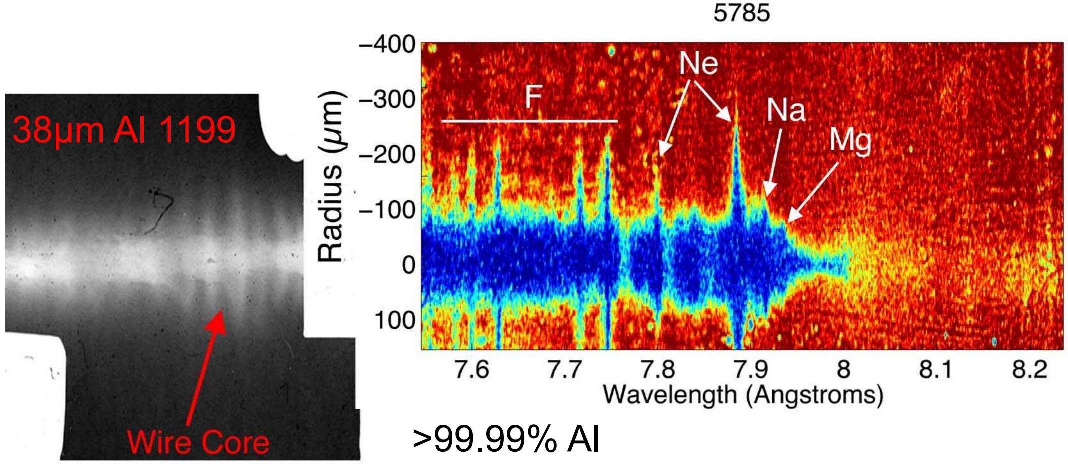
Simulated laser source spectrum reproduced from Iglesias et al., JQSRT 99 (2006)

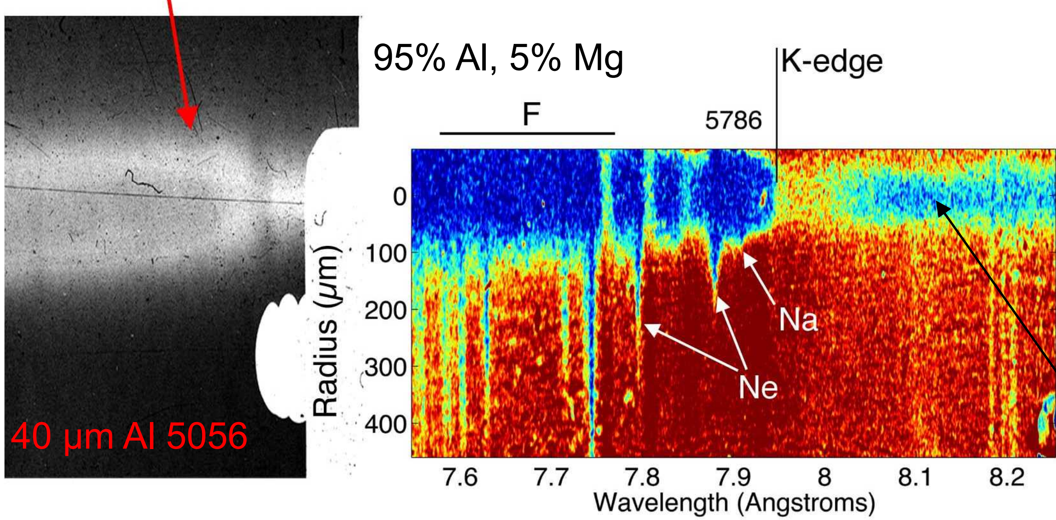
Understanding the Data



Single Exploding Wire Results

150 kA peak Current through single Al wire

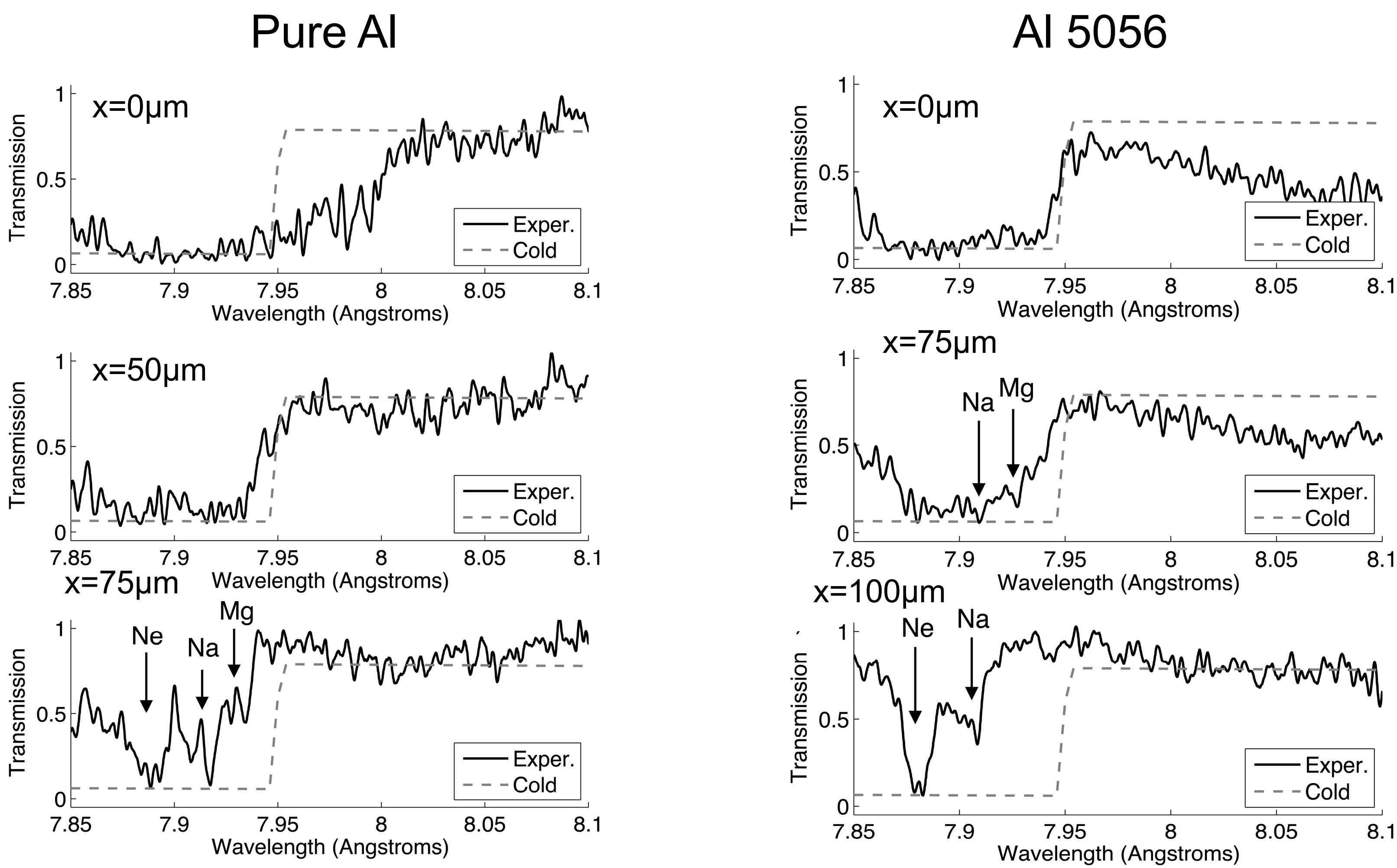




Increased absorption due to?

- Broad K-edge in pure Al
- Sharp K-edge in Al 5056
- Al 5056 exhibits tube-like wire core
- Al 5056 cold dense core w/ fast transition to plasma
- Pure Al core smooth transition to higher T_e
- Possible difference in initiation process

Single Wire K-edge Structure



Parallel Exploding Wires

Purpose

- Model physics of wire arrays on a small scale
- Simultaneously view coronal, streaming and stagnating plasmas
- Provide high fidelity data for comparison with RMHD models

Advantages

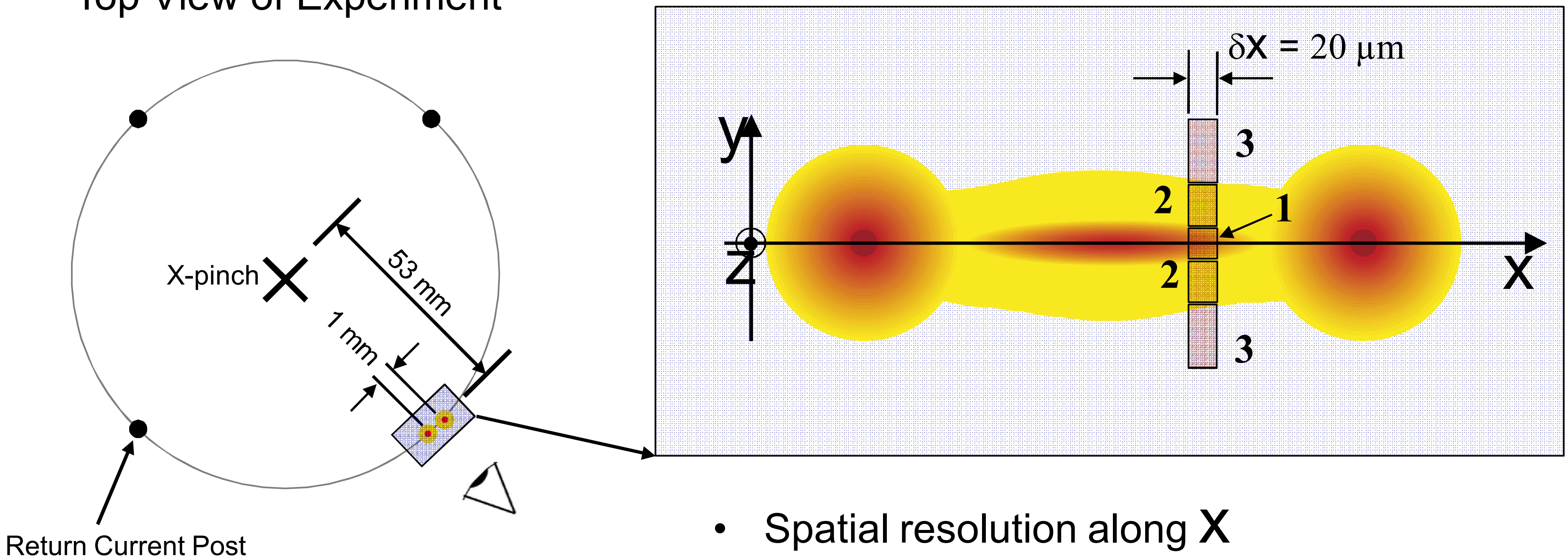
- Eliminates pinching seen in single wires
- Able to study streaming plasma

Disadvantages

- Complicated structure, gradients
- Lack of azimuthal symmetry

Two Parallel Al Wires

Top View of Experiment



- Spatial resolution along x
- Absorption path (LOS) parallel to y
- Three plasma regions to model gradients
- Symmetric about $x = 0$

Spectral Modeling

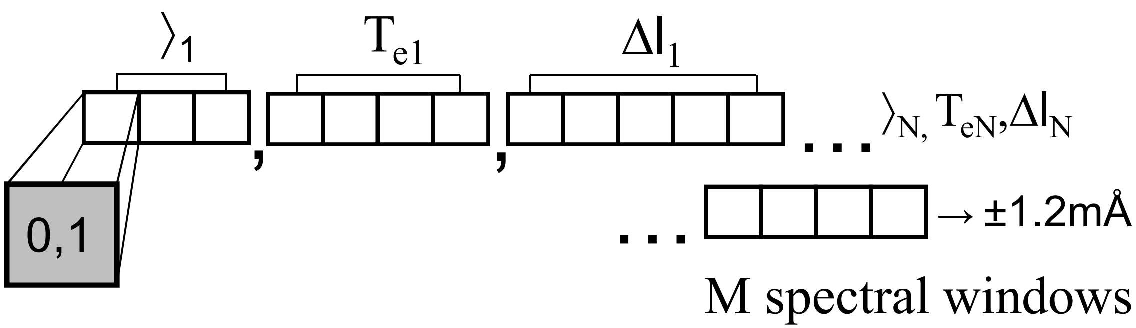
- Use opacity table calculated using the Hybrid Collisional-Radiative code SCRAM[3]
- Need to find T_e, ⟩ and Δl to fit the spectra properly

$$T_\nu = e^{-\rho\kappa_\nu(T_e,\rho)\Delta l}$$

- Weighted χ^2 to determine best fit at each spatial location

$$\min \chi_r^2 = \frac{1}{N-d}\sum_i^N \frac{1}{\sigma_i^2}\left(T_i^{\exp} - T_i^{syn}\right)^2$$

- Use Genetic Algorithm to find optimum fit w/ 3 regions



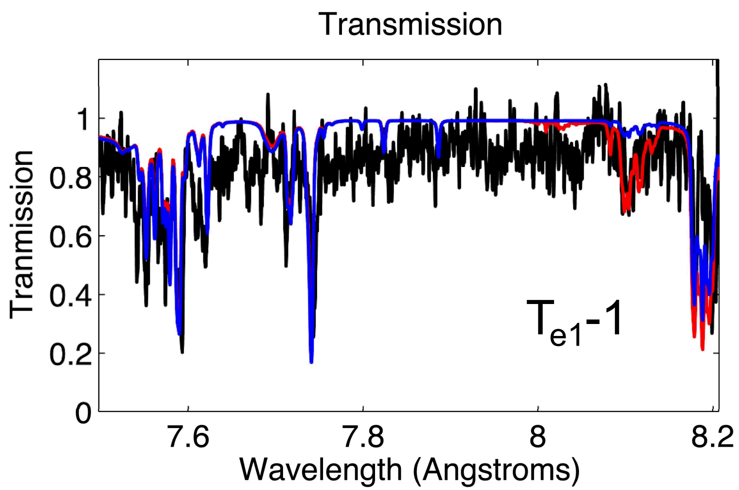
⟩: 2.7x10^{-4}→2.7 g/cc
T_e: 1 → 100 eV
Δl: 1 → 500 μm

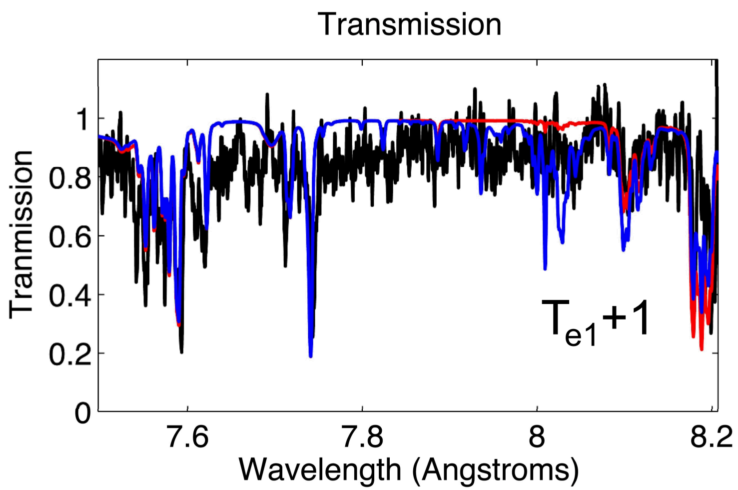
$$T_\nu^{syn} = T_\nu^1 \times T_\nu^2 \times T_\nu^3$$

[3] S.B. Hansen et al., High Energy Dens. Phys. 3 (2007) 109

Estimating Errors

- Error in T_e measurement is better than ±25%
- Limited by grid spacing of opacity calculation





These values produce spectra that obviously do not fit
Similar procedures provide estimates for ρ and Δl

ε_ρ=+100%/-50%

$\varepsilon_{\Delta l}$=±40%

COBRA Shot 2030

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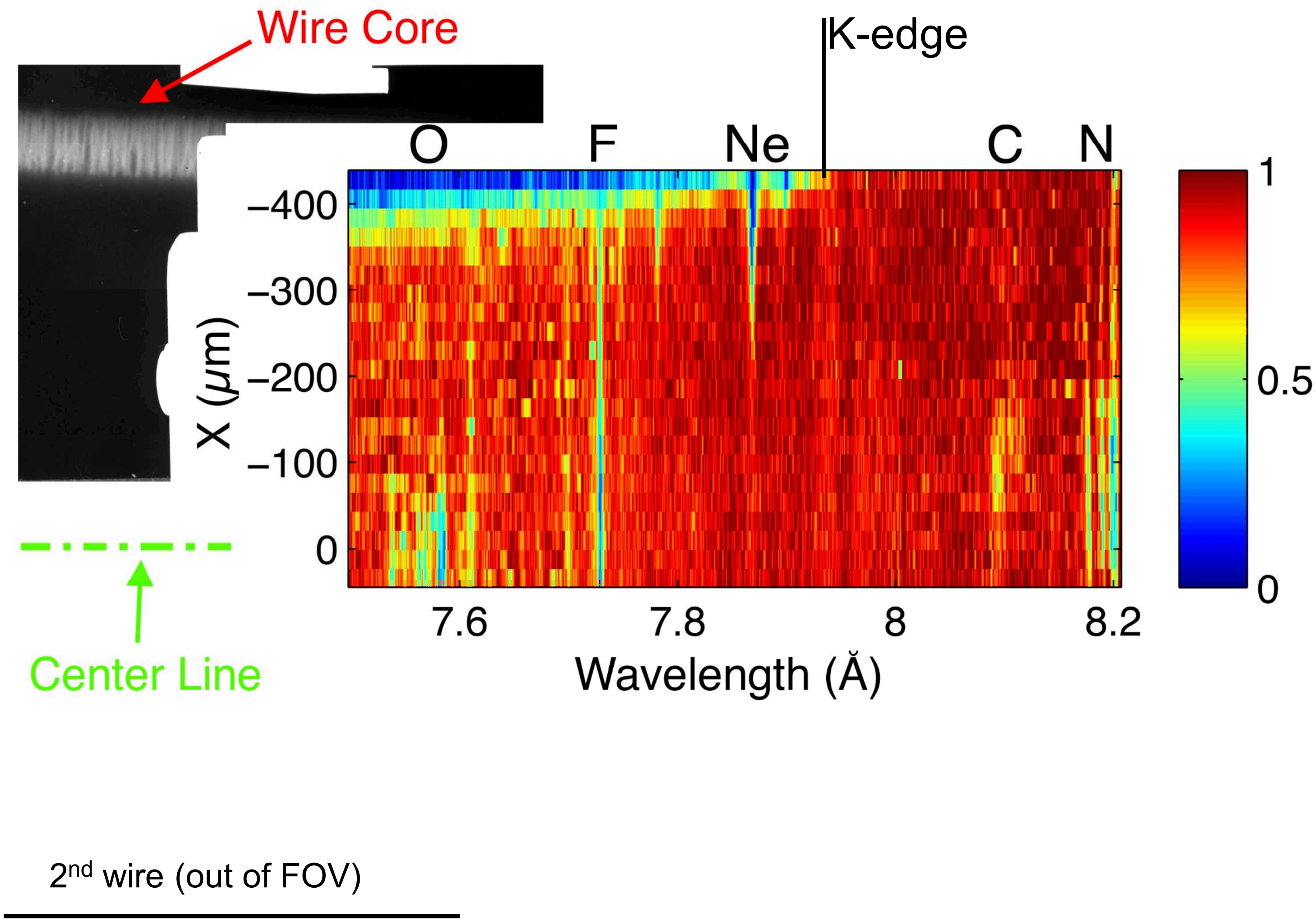
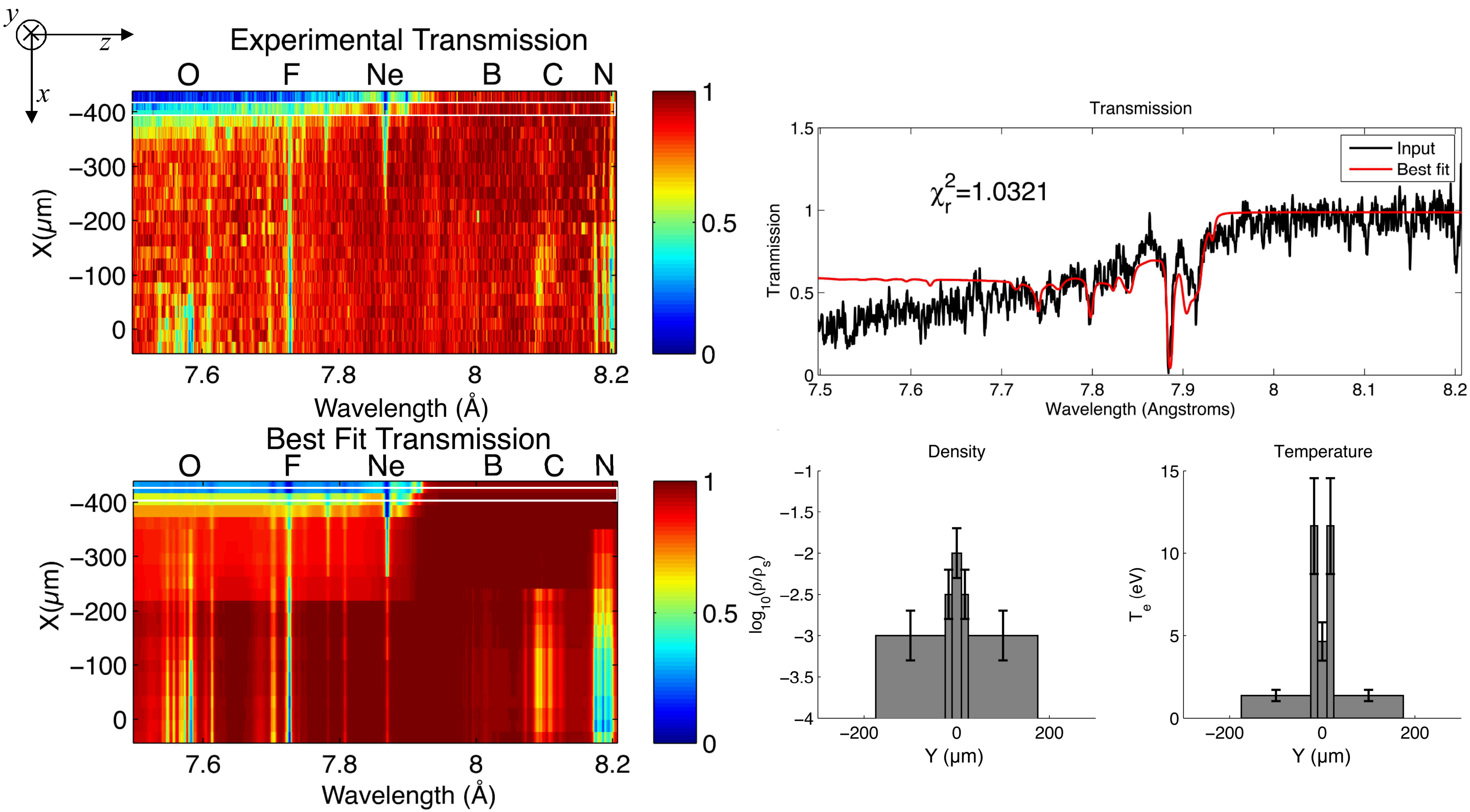
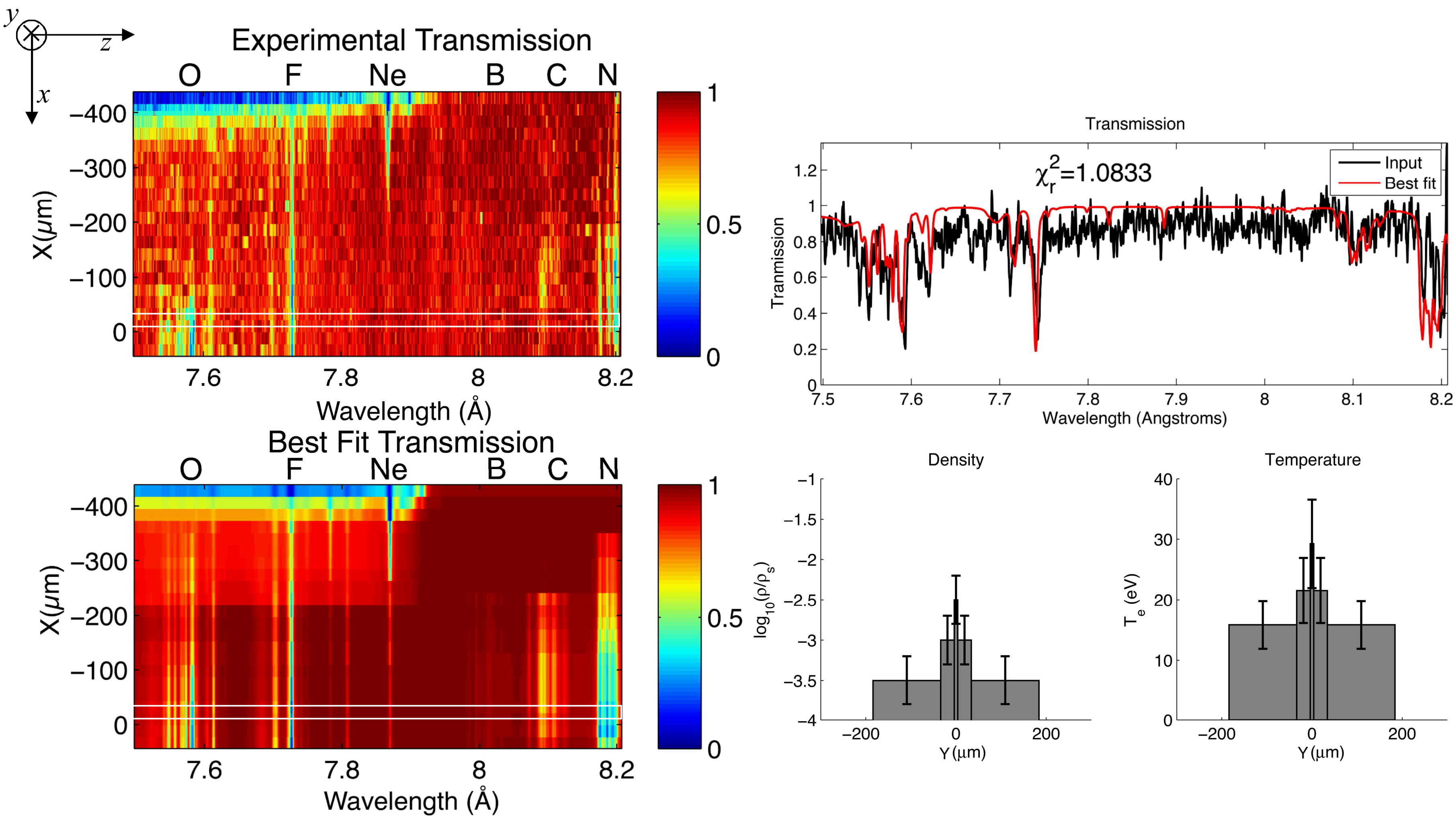


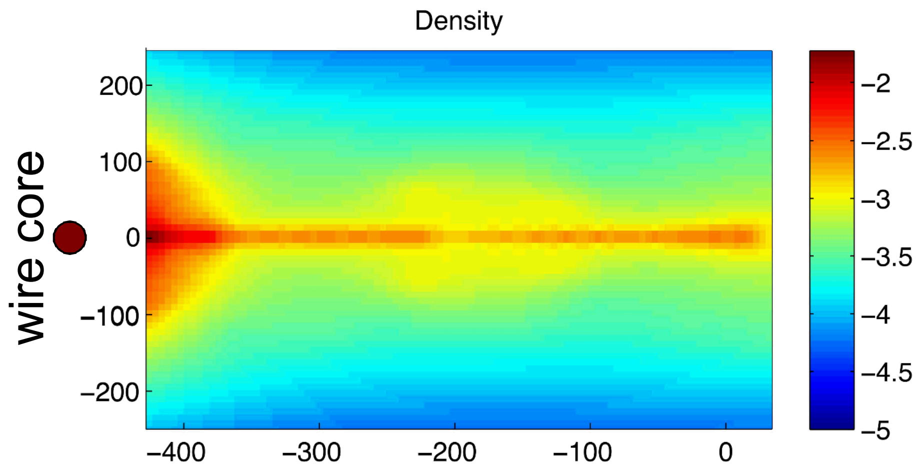
COBRA Shot 2030



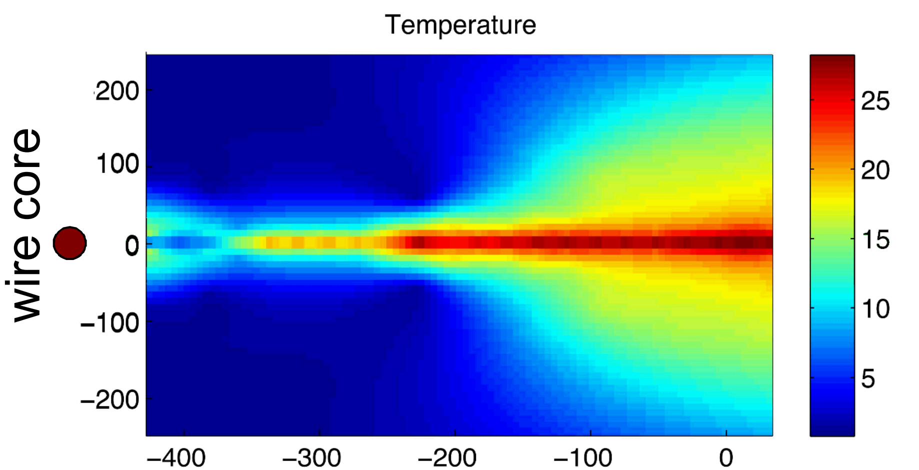
COBRA Shot 2030



2D ρ and T_e maps



- Peak density ρ=0.027g/cc (n_i=6x10^{20} cm^{-3}) (+100%/-50%)
- Highest density near core
- No clear evidence of increase in density at center line



- Peak Temp. T_e=29±7eV
- Hotter(15eV) coronal plasma visible around core(8eV)
- T_e increases near center line

Conclusions

- First spatially resolved measurements of T_e in coronal plasma up to edge of wire core
- Inferred peak T_e of 29eV at the center line
- Peak densities of $6x10^{20}cm^{-3}$ at edge of wire core
- $T_e \leq 10$eV at edge of wire core
- T_e=15-20eV in coronal plasma
- Able to infer parameters varying in two dimensions using assumptions
- Showed plausible T_e and ρ maps generated by the GA

Alternate Slides

First Measurements Near Wire Core

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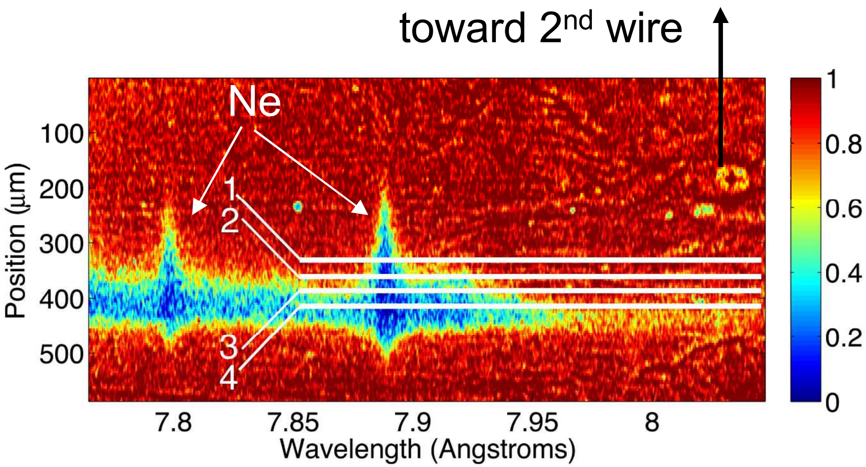
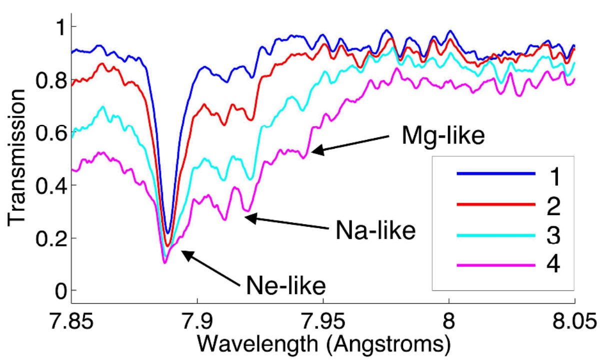


Widths of Ne-like lines vary dramatically with distance

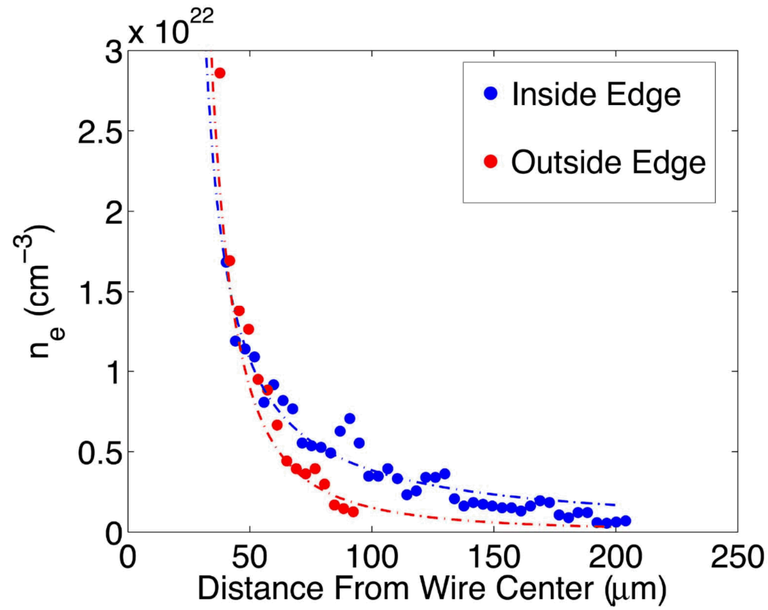
1: > 10eV

4: < 4eV



Using approx. Stark broadening formula

$$\delta\varepsilon_s(eV) = 4.3\frac{n^2}{Z_{nuc}}\left(\frac{n_e(cm^{-3})}{10^{22}(cm^{-3})}\right)^{0.58}$$



- Follows 1/r, $1/r^2$ dependence
- T_e increases faster outside than inside

COBRA Shot 2034