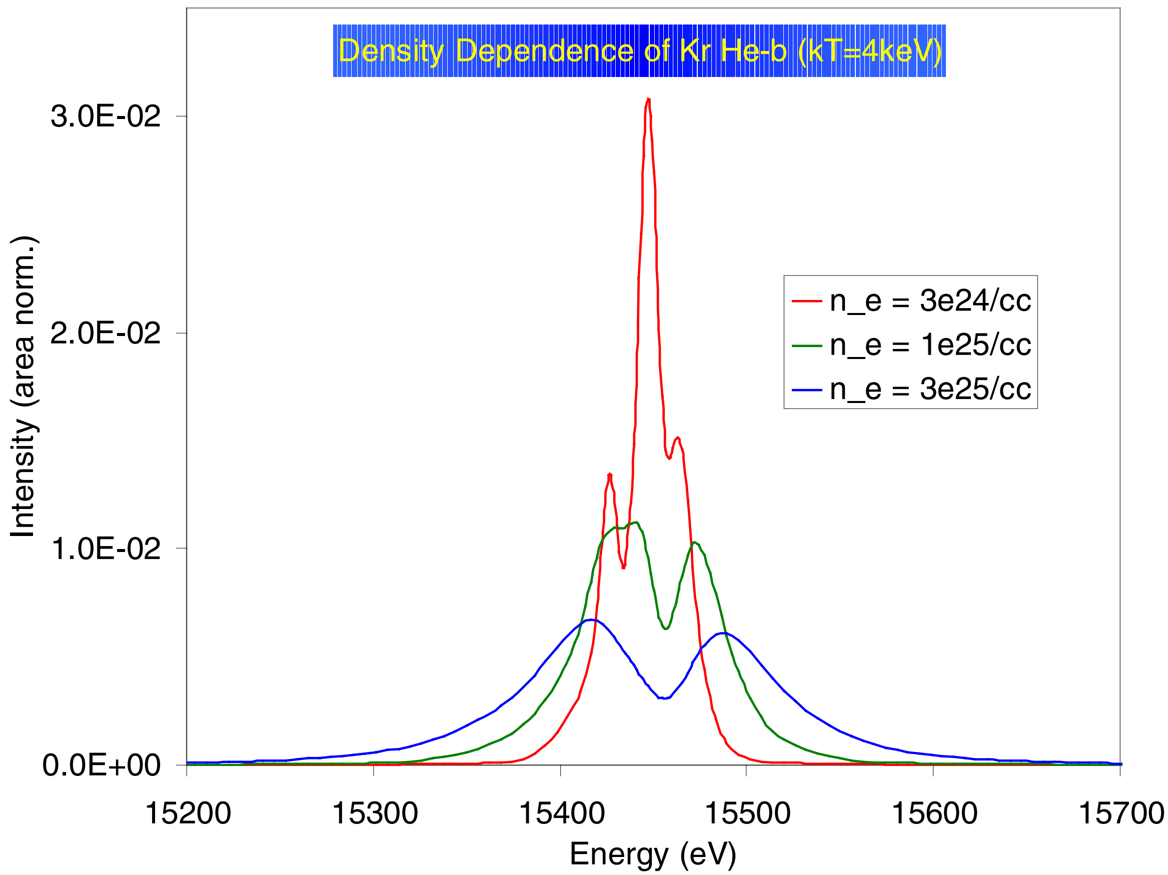
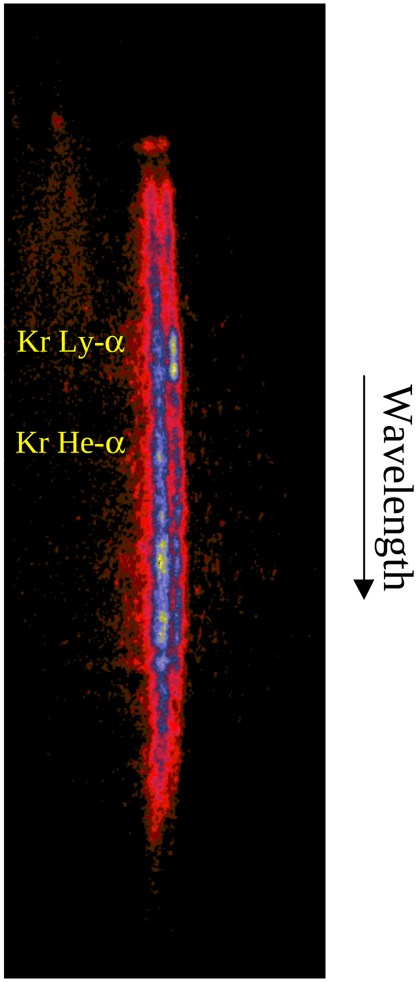
Time-resolved Kr K-shell Spectroscopy of Directly-Driven Microballoon Implosions: Theory and Experiment





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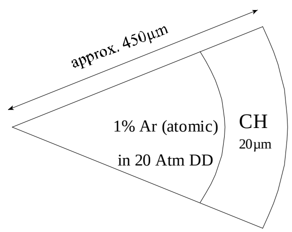
Summary and Outline

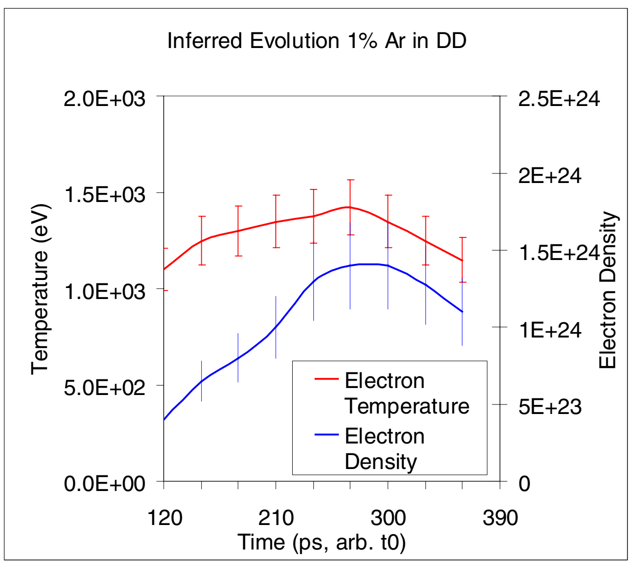
Time-resolved Kr line emission has been observed in directly-driven microballoon implosions, and can serve as a useful diagnostic to probe regions of interest for neutron generation inaccessible to Ar line emission

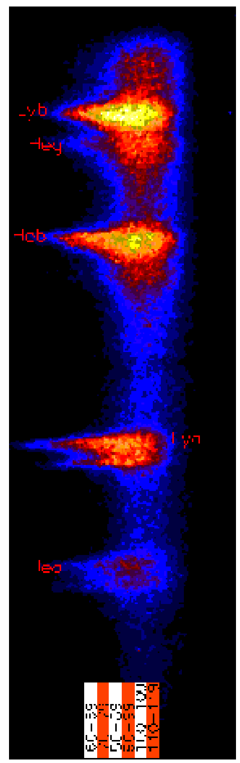
- Motivation
  - Previous Ar doped implosion results
- Experiment
  - Design
  - Instruments
  - Data reduction
- Theory
  - Stark broadened Kr K-shell line shapes
  - NLTE Kr populations

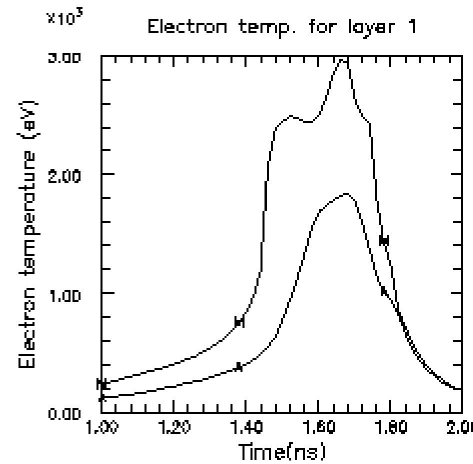
Motivation

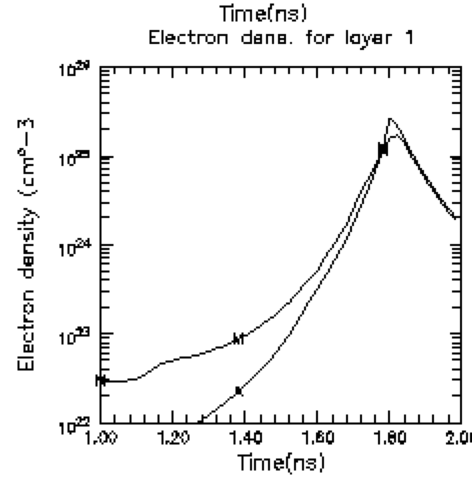
•Diagnostic access to the hottest, densest regions of microballoon implosions where Ar lines cannot be used.







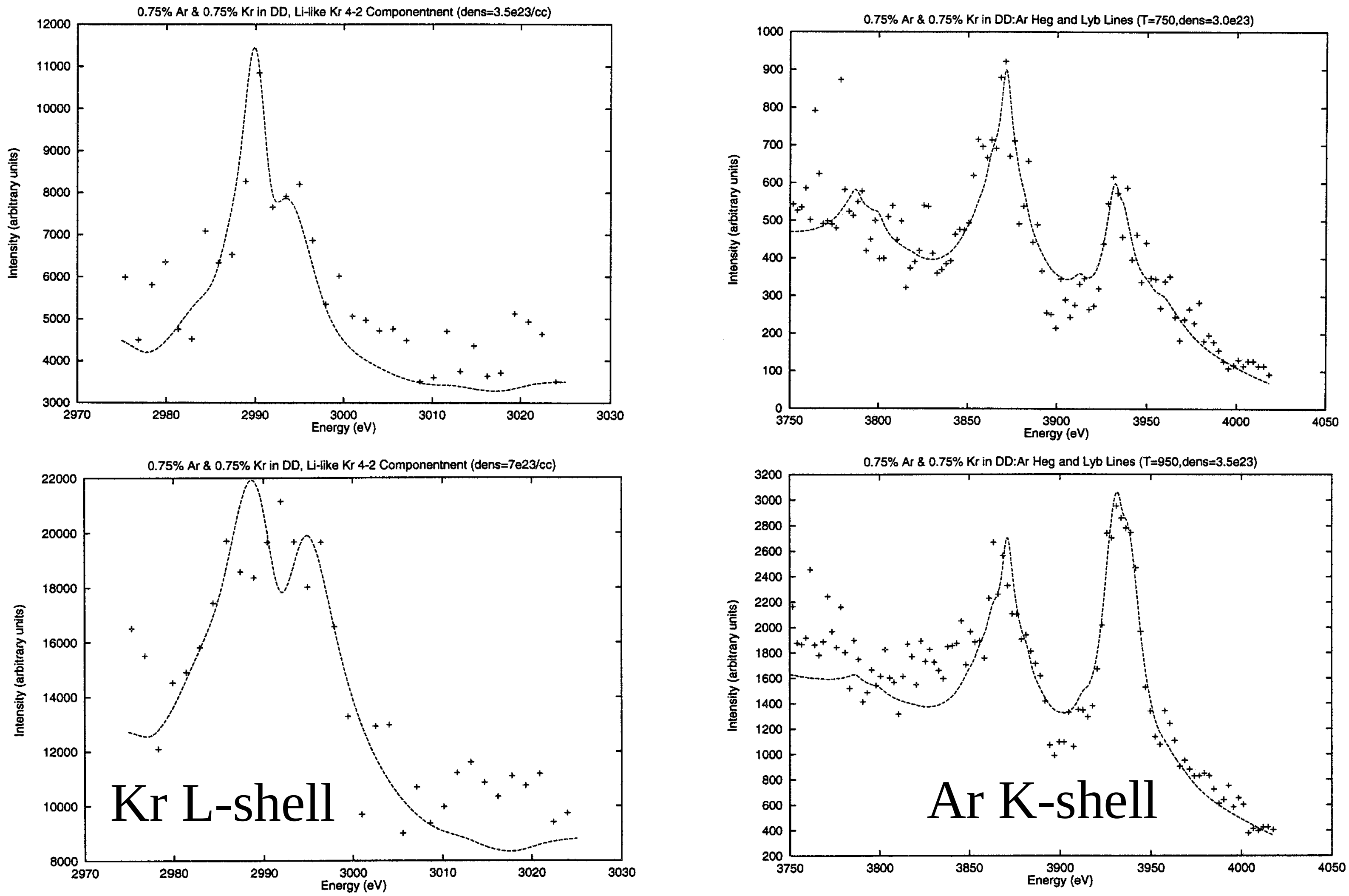




DAH : DPP99

In this case, the temperature inferred from Ar line emission peaks at half the predicted value, though YOC was 1/3.

Motivation (cont.) As implosion proceeds, density inferences from Kr L-shell and Ar K-shell lines diverged.



DAH : DPP99

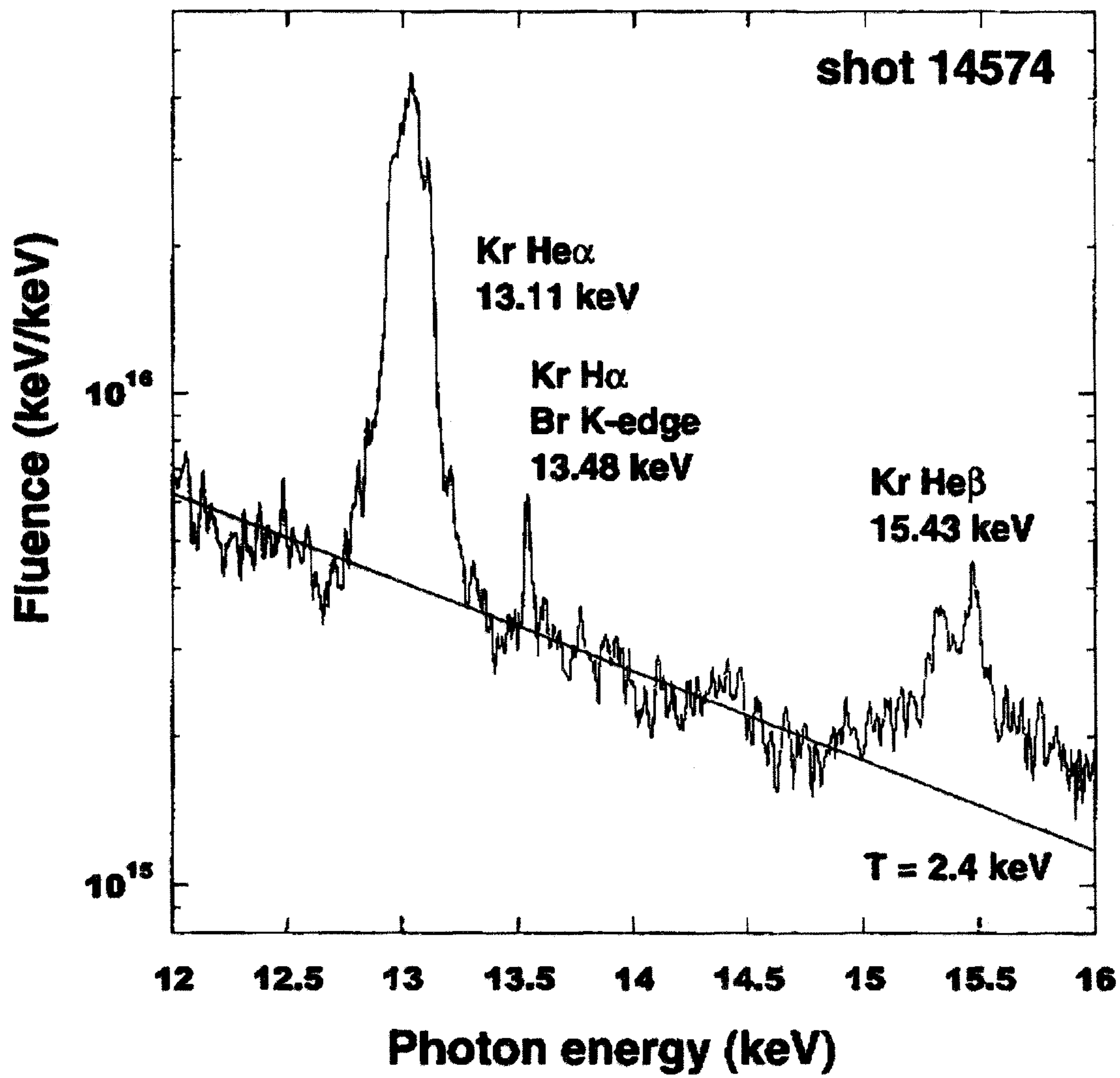
Time-resolved spectroscopy of argon, krypton, and xenon x-ray lines from laser-produced plasmas, G. Junkel, M. Gunderson, D. A. Haynes, Jr. and C. F. Hooper, Jr., presented at the 38th Annual Meeting of the Division of Plasma Physics, November, 1996.

Motivation (cont.): B. Yaakobi of LLE has recorded time-integrated Kr K-shell lines

1% Ar/ 4% Kr in D_2 (20 Atm total), 15μm CH shell (918 μm OD).

Yaakobi, *et al.*, have suggested diagnostic uses for Kr lines in:

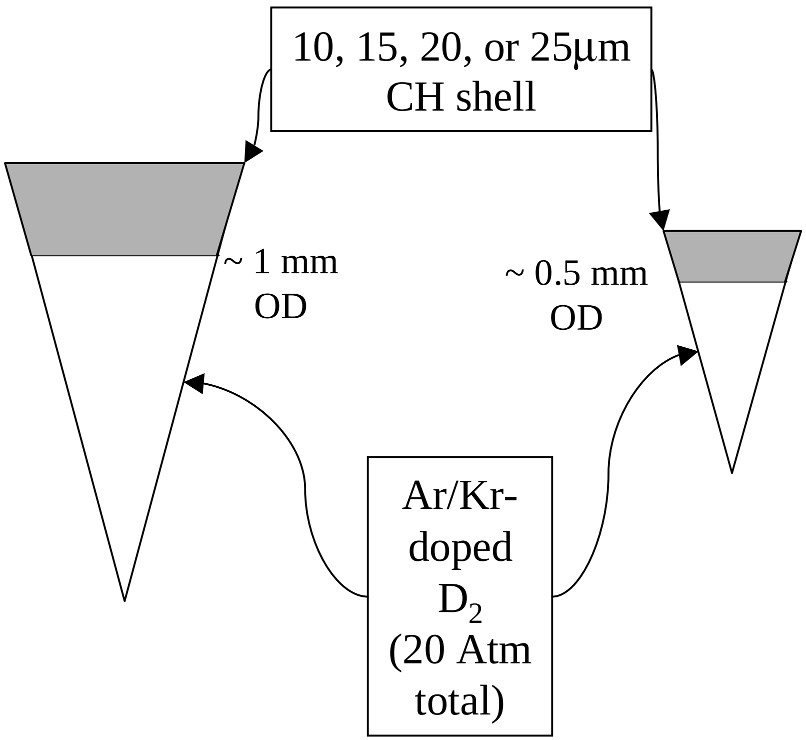
Diagnosis of high temperature implosions using high-opacity krypton lines, B. Yaakobi, R. Epstein, C. F. Hooper, Jr., D. A. Haynes, Jr., and Q. Su, Journal of X-ray Science and Technology **6** 172 (1996).



Motivation (summary)

- Even though YOC is 0.36, electron temperatures and densities inferred from Ar K-shell line emission are lower by factors of 2 and 10, respectively, from their predicted values:
    - Neutrons may be emitted from regions that Ar K--shell line analysis is not accessing.
- Simultaneous density inferences from Ar K-shell and Kr L-shell lines are similar at early times, but diverge at late times:
    - At late times, Kr lines are emitted from regions of higher density than the Ar K-shell lines.
- Yaakobi had shown that time-integrated Kr K-shell emission can be observed from directly-dirven Ar/Kr doped D_2 microballoon implosions.

Experiment: Design

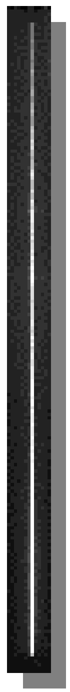


“Scoping” study

- Directly driven implosions using 60 beams of the Omega laser system, delivering approximately 27kJ to the target in a 1ns square pulse.
  - “small” targets were imploded using **unsmoothed** beams.
  - “large” targets were imploded using either smoothed or unsmoothed beams.

Experiment: Instruments

Kr K-shell

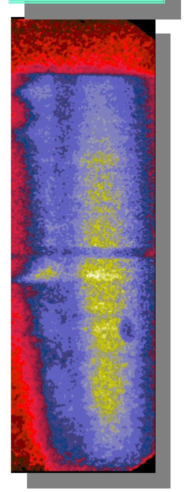


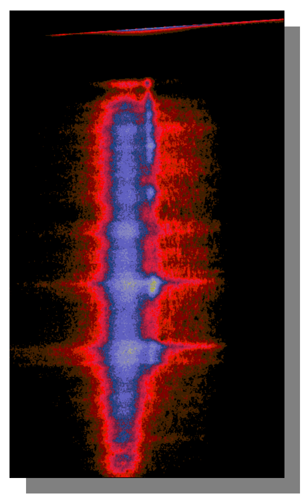
XRS:

Time-integrated crystal spectrograph

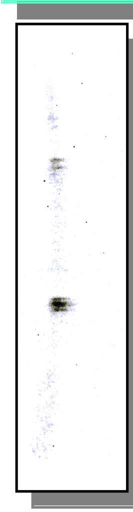
(LiF crystal, x-ray film)

Ar K-shell



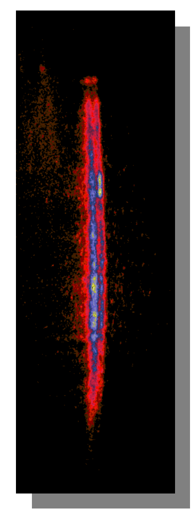


Kr K-shell



SSC:

streaked crystal spectrometer



LXS:

streaked crystal spectrometer

Data Reduction

Taking the LXS as an example, the time-resolved data was reduced as follows:

•Digitization (50μm X 50μm)

•Film Density to Intensity Conversion (Wedge Correction)

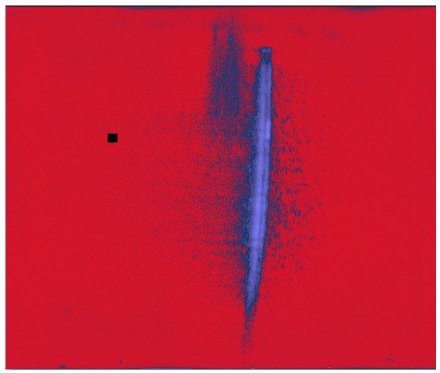
•Correction for known instrumental distortions (streak angle, and barrel correction).

•Sweep speed established by timing fiducial trace

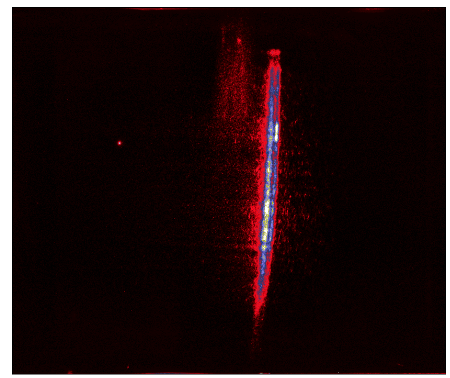
•Lineouts in spectral direction, averaging over time.

•Dispersion relationship established by line identification, constrained by known crystal 2d and geometry.

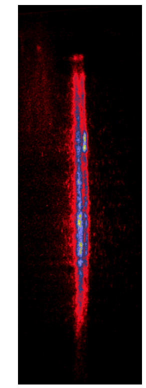
Data Reduction (cont.)



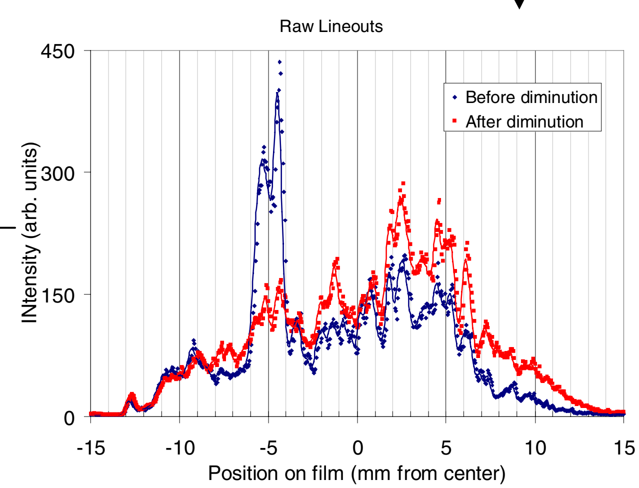
Wedge



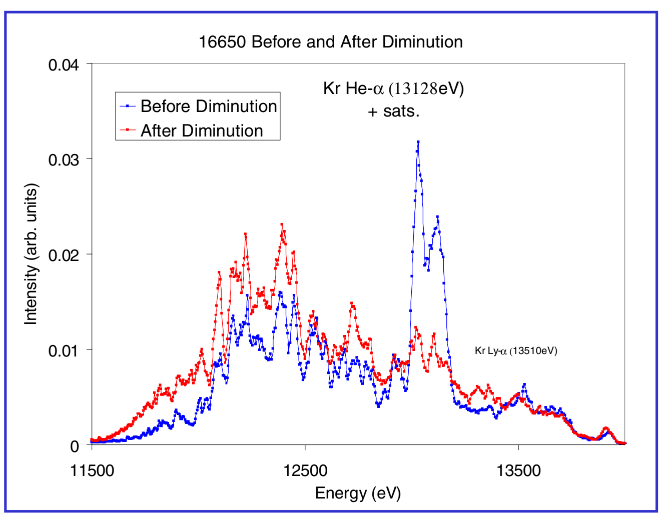
Distortions



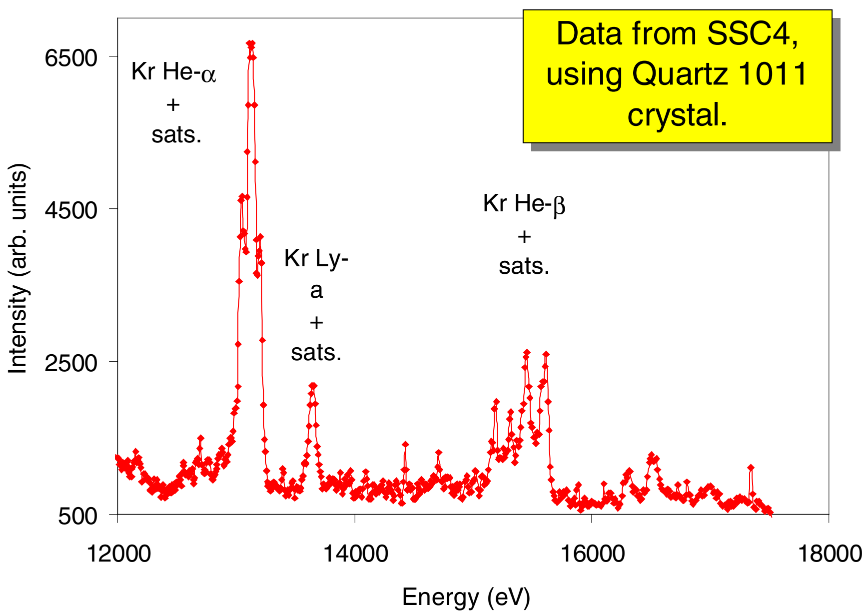
Lineouts

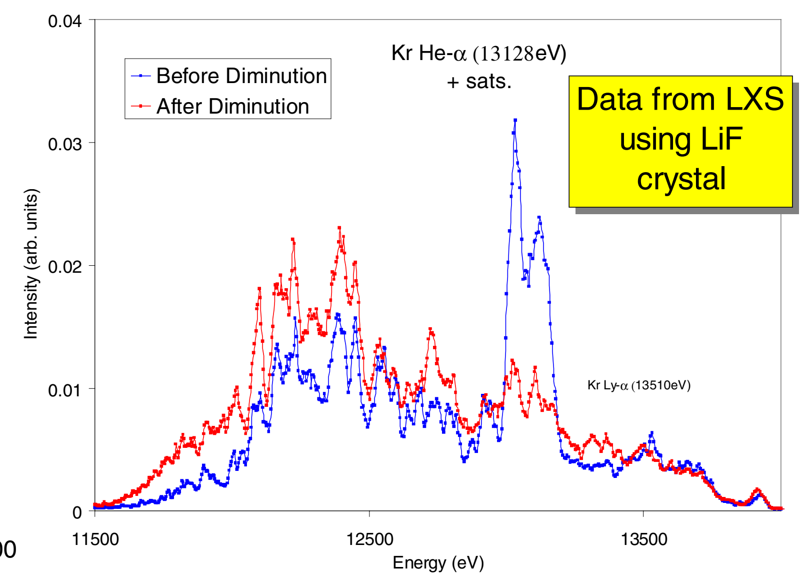


Dispersion



Data: Time-resolved Kr K-shell from two instruments



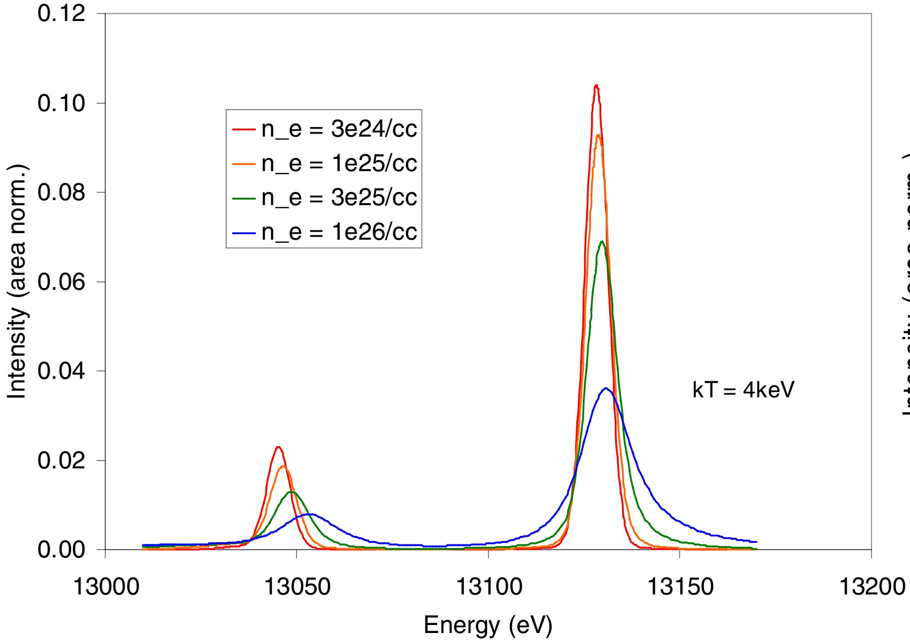


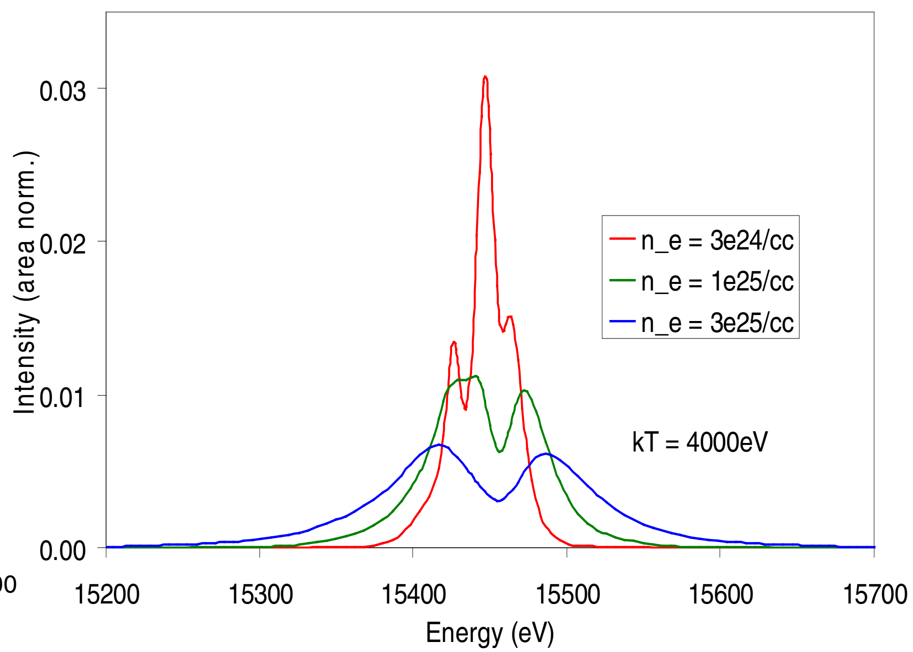
Smooth beams, 1mm OD, 15μm shell, 1%Ar / 4% Kr in DD (20Atm total)

Unsmoothed beams, 1mm OD, 10μm shell, 1%Ar / 2% Kr in DD (20Atm total)

Theory: Stark Broadened Kr K-shell resonance lines

$$I(\omega) = \int d\vec{E}\; Q(\vec{E})\; J\left(\omega ; \vec{E}\right)$$



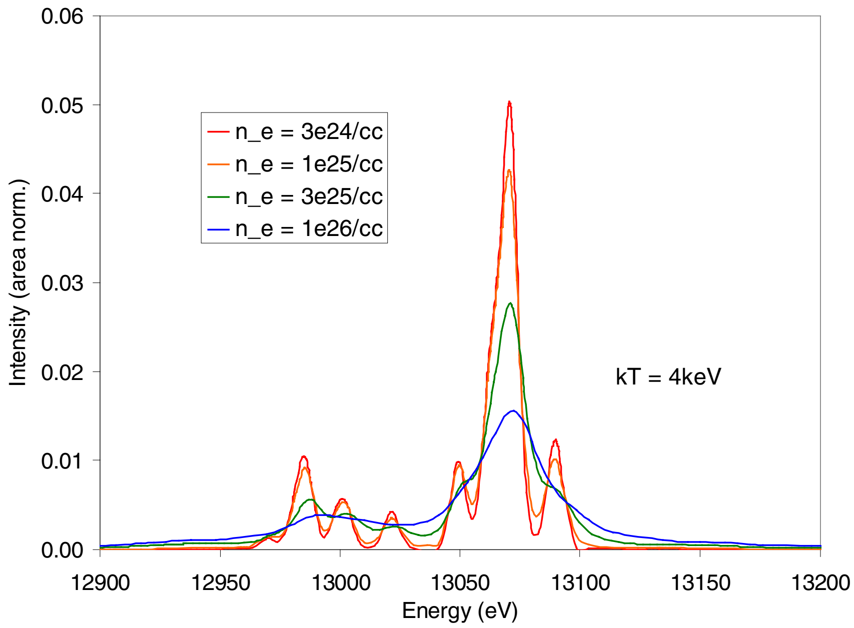


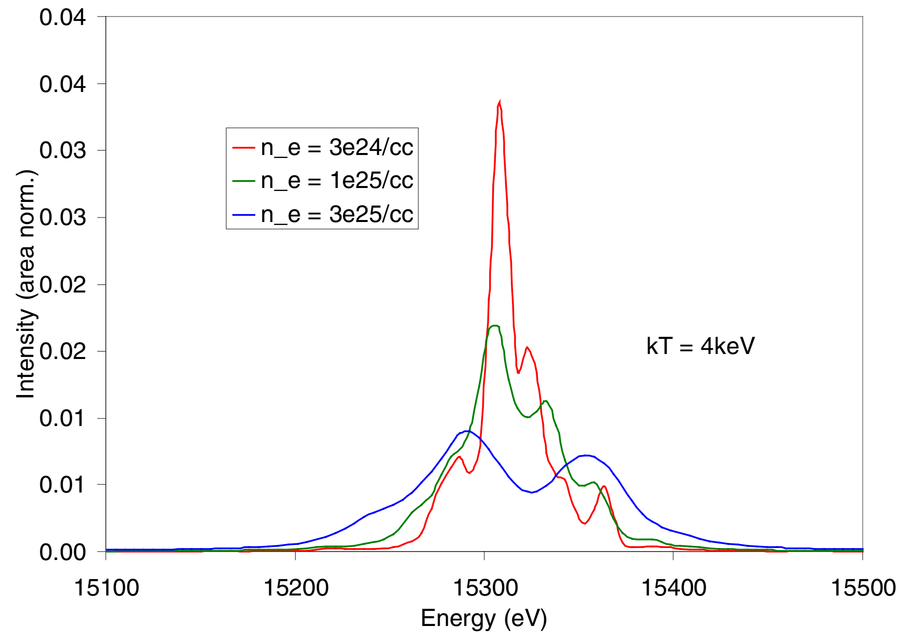
Kr He-α

Kr He-β

DAH : DPP99

Theory: Stark Broadened Kr satellites





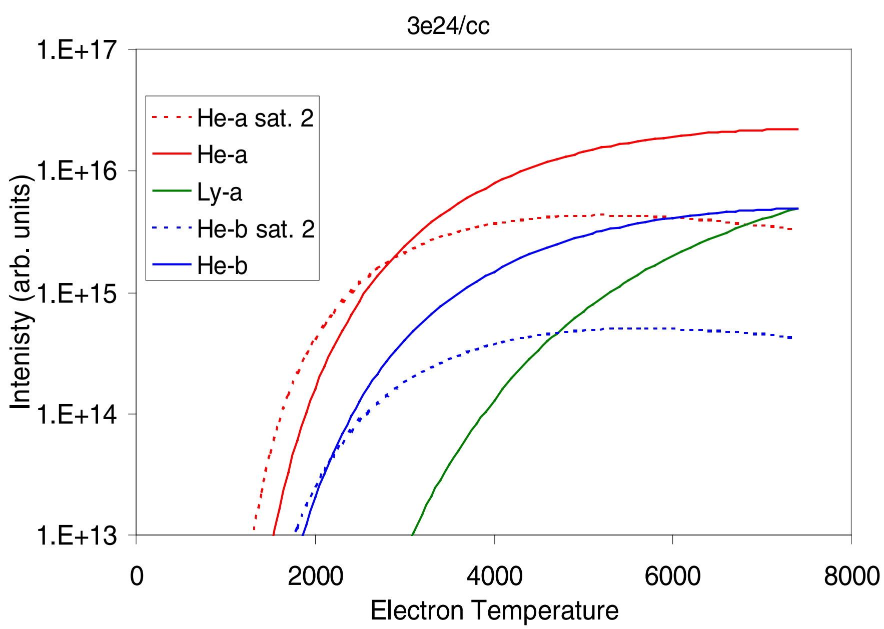
Kr He-α, sat. 2

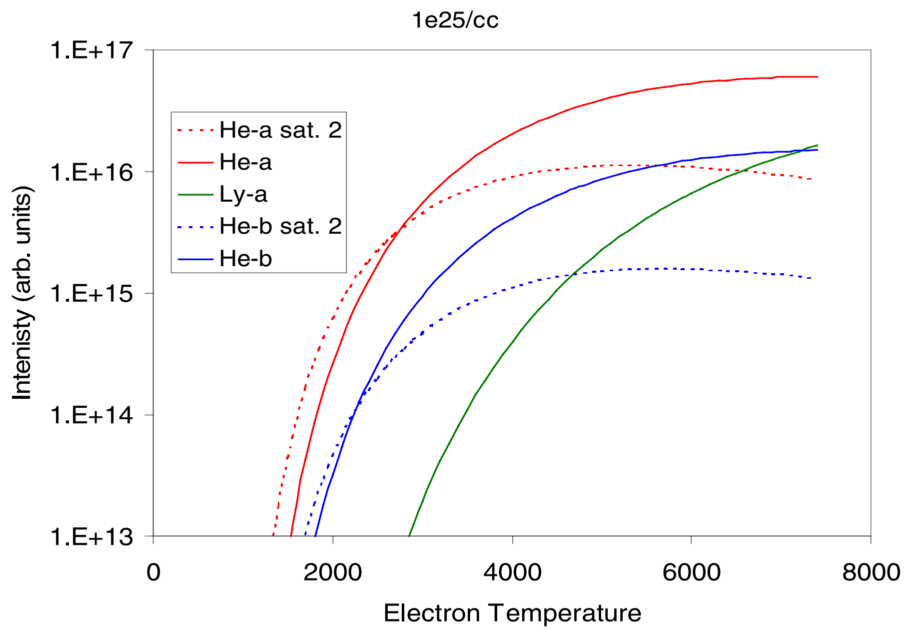
Kr He-β, sat. 2

DAH : DPP99

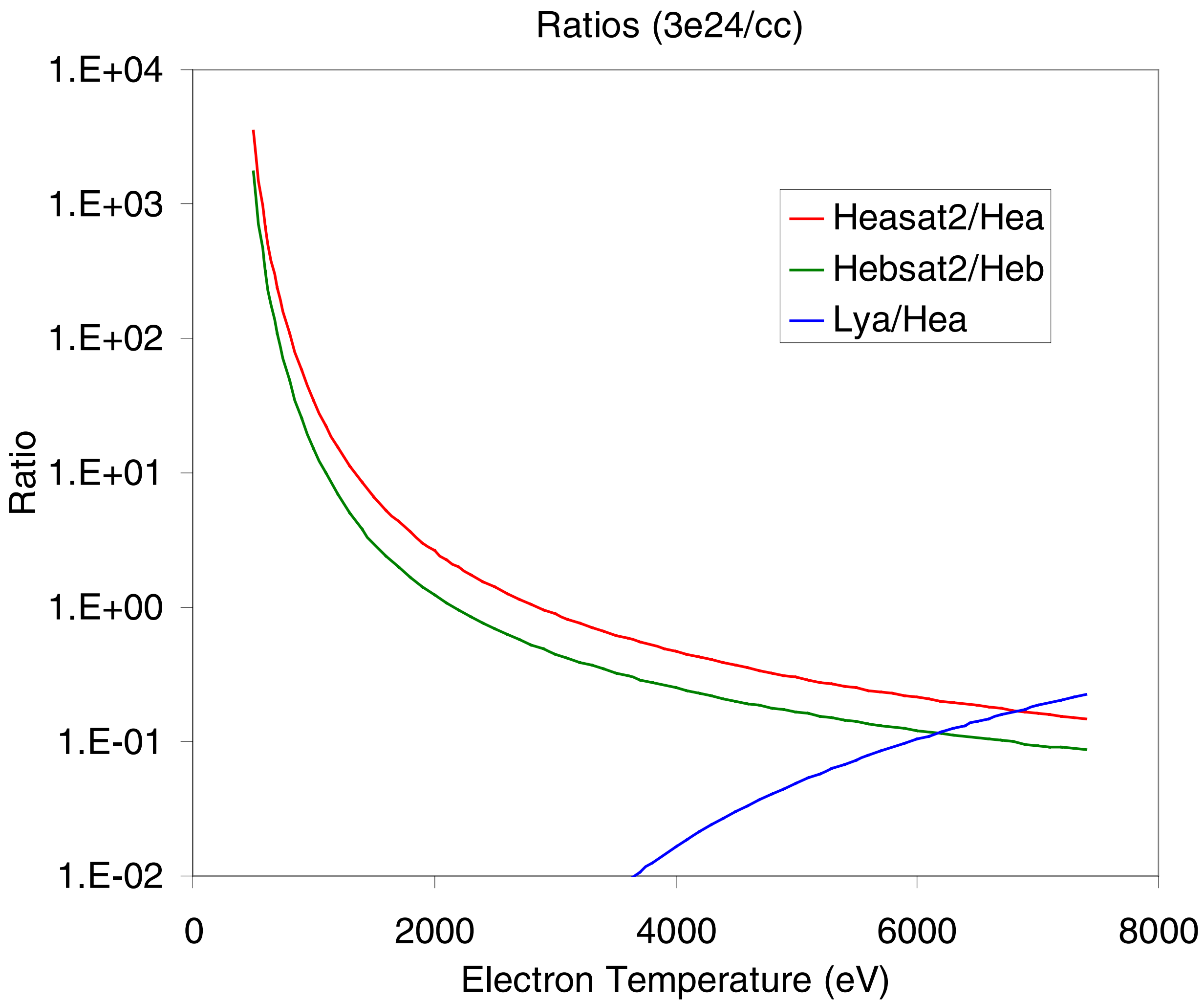
Theory: NLTE Kr K-shell Intensities

Kinetics calculations were performed using CRETIN (H.A. Scott and R. W Mayle, Applied Physics B **58** pp.35-43 (1994)), and a 1194 level Kr model obtained from N. Delamater (LANL). The authors wish to thank Drs. Scott and Delamater for their invaluable assistance.





Intensity Ratios of Kr K-shell lines and Satellites may form a useful diagnostic for temperatures at which Ar is largely fully stripped.



DAH : DPP99

Summary and Conclusions

- Peak n_e and kT_e inferences from Ar line emission analysis are difficult to reconcile with observed YOC.
- Ar K-shell lines and Kr L-shell lines, recorded simultaneously on the same spectrometer are characteristic of different densities, with the Kr lines characteristic of higher densities.
- Kr K-shell lines have been observed using streaked spectrometers.
- The Kr He-β line displays diagnostically useful density dependence for n_e >3e24/cc, and ratios of He-like likes to their satellites or to H-like lines will provide a useful temperature diagnostic for $kT_e > 2$ keV

Time-resolved Kr line emission has been observed in directly-driven microballoon implosions, and can serve as a useful diagnostic to probe regions of interest for neutron generation inaccessible to Ar line emission