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Effects of a Xe Dopant on an Ar gas-puff implosion on Z*

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Doping the center jet of Ar gas-puff shot Z2603 with 0.8% Xe had a strong effect on its K-shell yield and other properties, compared to the otherwise identical, but non-doped shot Z2605. 1% Kr is present in both shots.

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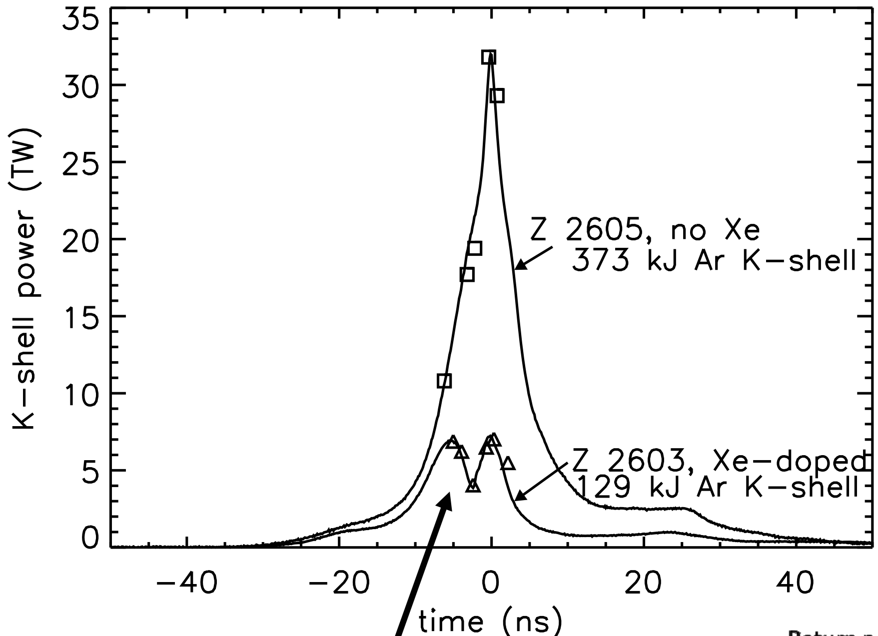
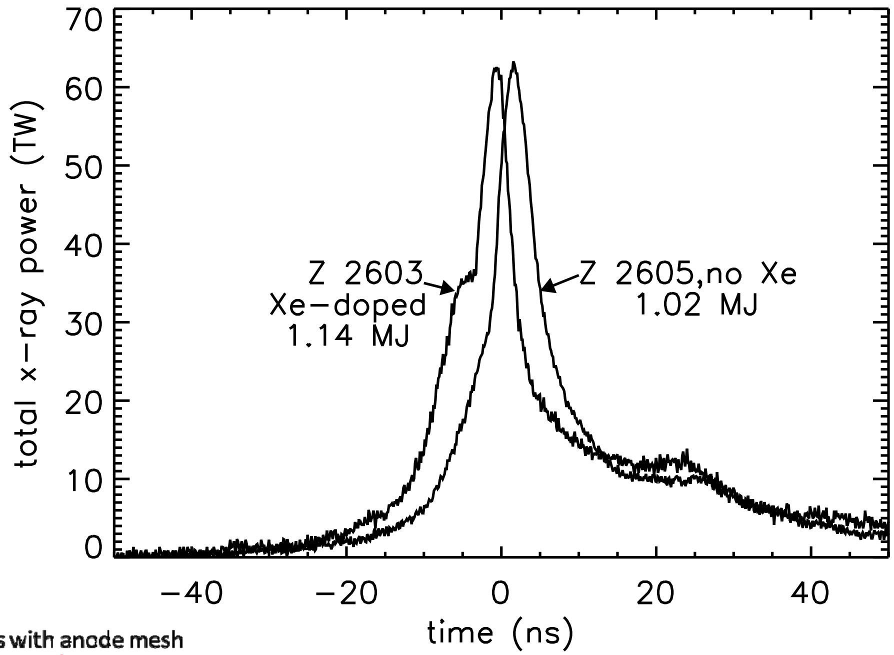
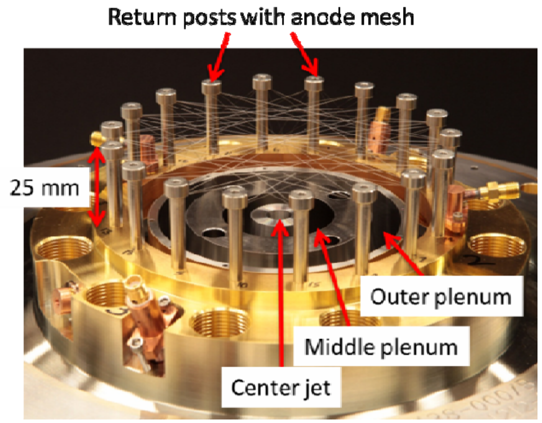




Note double-peaked K-shell pulse. Squares and triangles are from analytic multivariate fit to model results (slide 12 below).



For both shots:

Mass load: 1.2 mg/cm

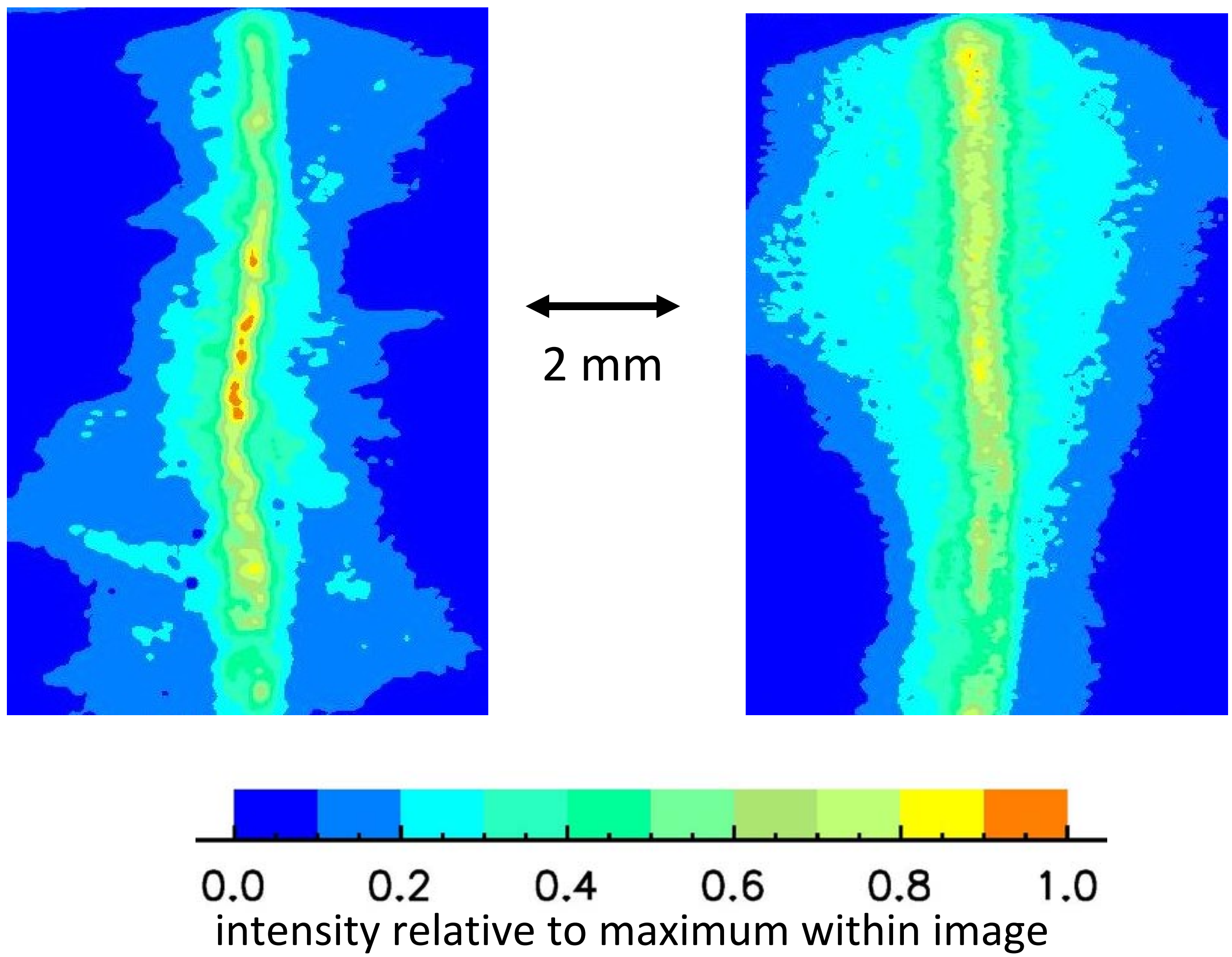
(0.385 : 0.615 : 0.2)

peak current: ~ 15 MA

The Xe-doped shot Z 2603 had half the K-shell diameter at stagnation compared to the non-Xe-doped shot Z 2605.

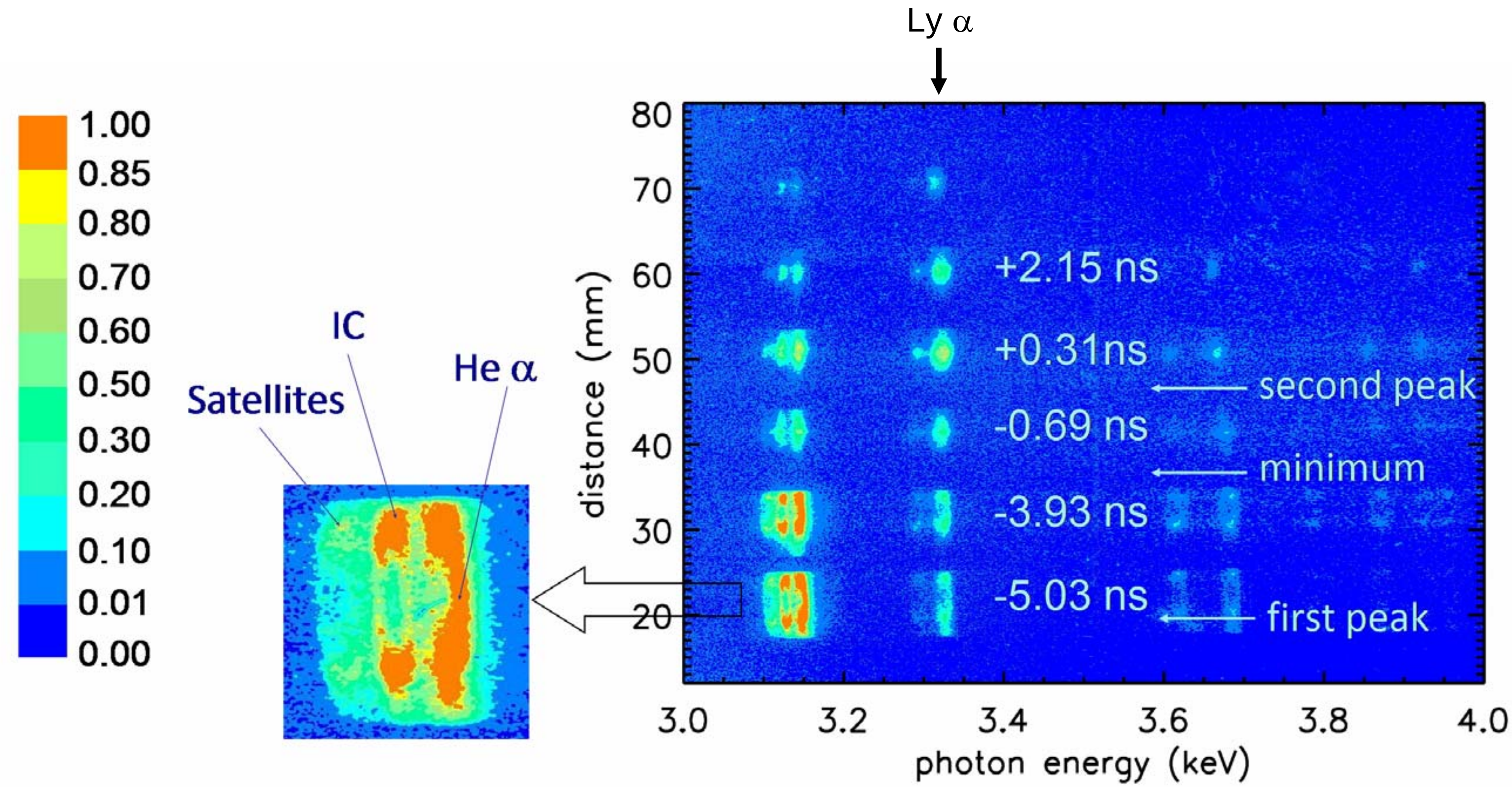
Z 2603 (Xe-doped)
diameter 0.62 mm

Z 2605 (no Xe)
diameter 1.20 mm



To investigate these interesting phenomena, properties of the Z2603 and Z2605 pinches have been inferred from time- and radially-resolved K-shell spectroscopy at 5 different times.

Z2603



Time- and radially-resolved K-shell spectra for Z2605

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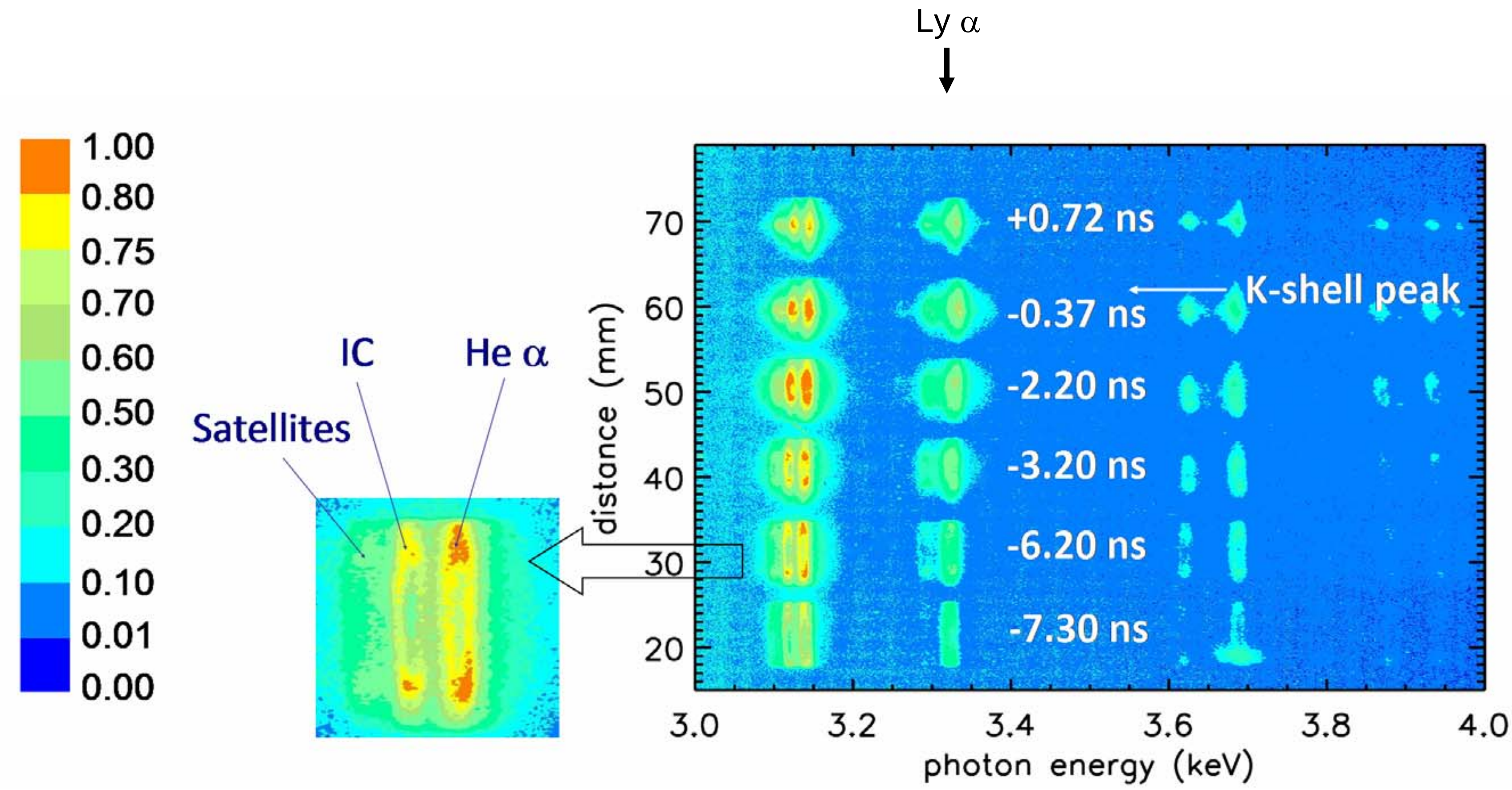
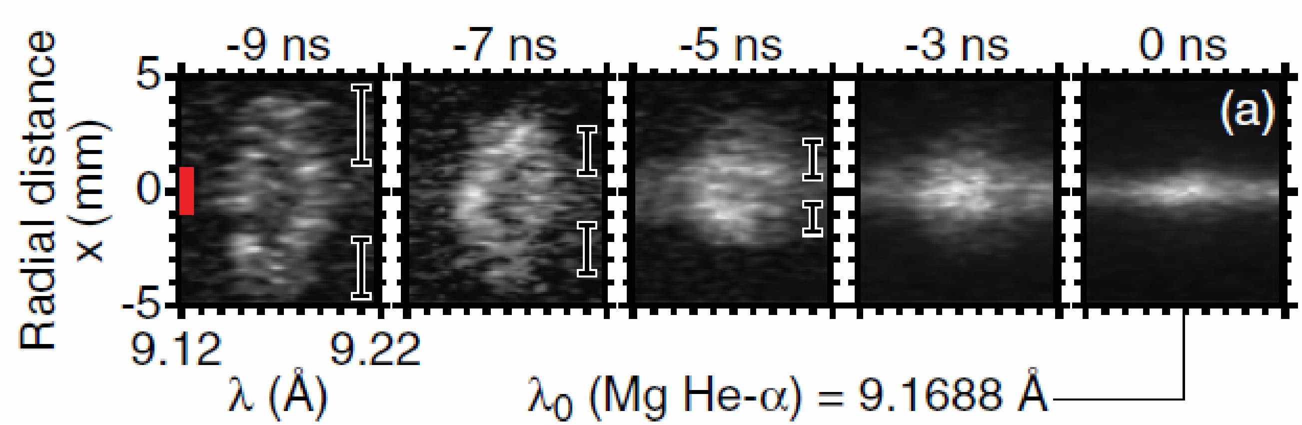
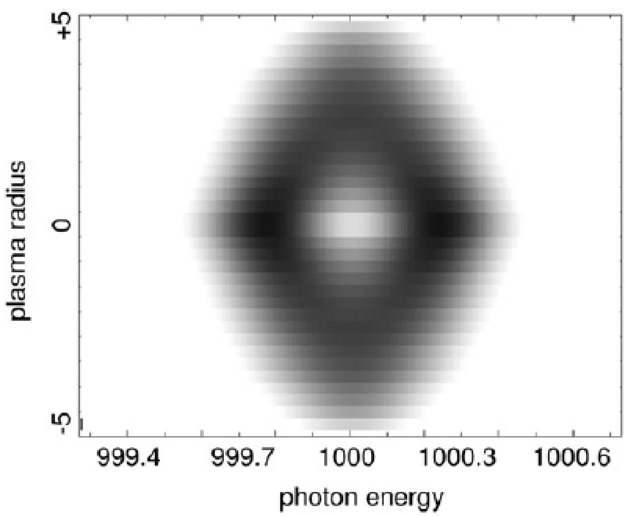
Z2605



In the early frames of both shots, the optically thin intercombination (IC) line exhibits the classic oval structure due to Doppler splitting. This phenomenon has previously been observed in and calculated for imploding Z pinches.

Observed in Al:Mg wire array (Z1520) [Jones *et al.,* Phys Rev.E **84**, 056408 (2011)]

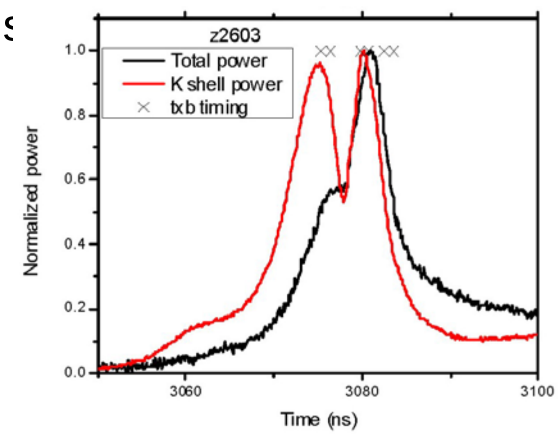




Calculated by Hansen *et al.,* High Energy Density Physics **7**, 303 (2011). The components are offset from line center by (± v/c)E_0.

What can be learned directly from the data and/or inferred by fitting it with models?

- An implosion velocity can be obtained from the rate of shrinkage of the K-shell x-ray image. This will, however, be influenced by ionization waves in addition to the true particle implosion velocity (Jones *et al.,* Phys Rev.E **84**, 056408 (2011)])
- The particle implosion velocity of the He-like ions can be obtained from the Doppler splitting of the oval-shaped IC line prior to stagnation.
- The electron temperature, and the ion density in the K-shell emitting region can be inferred by simultaneous model fits of the measured K-shell power, a temperature-sensitive line ratio, the measured size of the K-shell region, and the total mass load.
- Note that there is no TREX spectrometer time-resolved frame that coincides or nearly coincides with, the K-shell minimum between the two nearly equal peaks of Z2603. However, a plausible scenario derived from interpolation is suggested by the present analysis



The experimentally measured K-shell sizes (± 15%) and implosion velocities from the K-shell images are shown below. Also noted are velocities obtained from the Doppler line splitting. ***Slower image shrinkage for Z2605 could be an effect of faster growth of the K-shell zone due to the lack of Xe radiative cooling in this shot.***

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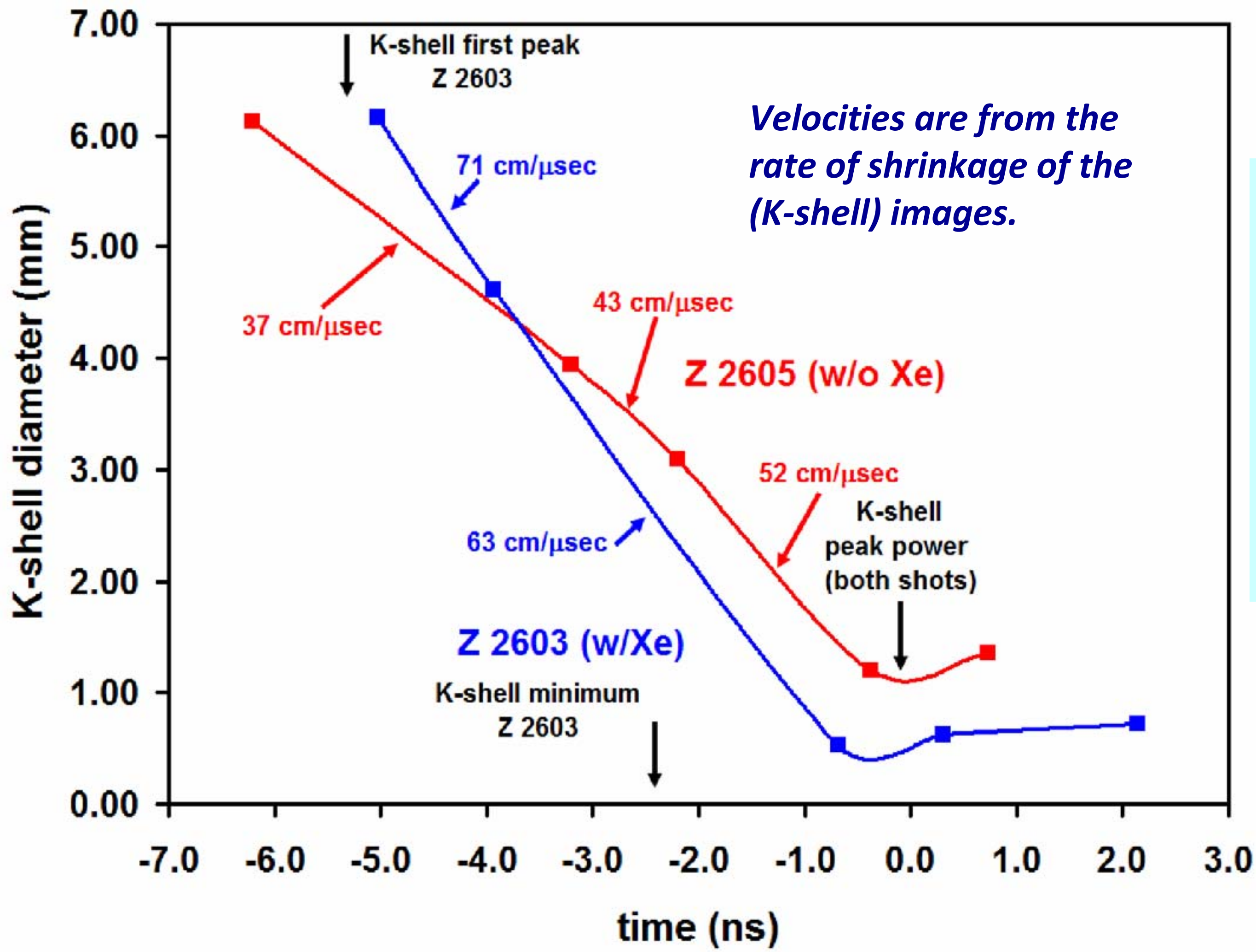

Velocities from line Doppler shifts

Z2603
-5.03 ns: 69 cm/µsec

Z2605
-6.20 ns: 65 cm/µsec
-3.20 ns: 65 cm/µsec

Fitting model calculations to x-ray data to infer pinch conditions

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- The pinch is assumed to consist of 2 or 3 cylindrical zones: a hot K-shell radiating core of the measured diameter surrounded by an 8 mm diameter blanket. For the first two frames, a "hollow core" is also included.

- Preliminary fits from a fast model[1] were recalculated and fine-tuned using a more detailed, 186-level, 611-line model that transports 15488 photon energies to resolve the line profiles. The quantities fitted are: the K-shell power, the mass load, and the Ly α/(He α+IC) ratio. The best overall fit (minimizing χ^2) is selected. Minimizing χ^2 maximizes the confidence level that the fit is significant.

- The effective ion temperature is generally not measurable; it has been set to 20 keV, roughly consistent with measurements on other Z shots and with values in the literature[2,3] for high-current gas-puff shots.

1. J. P. Apruzese, K. G. Whitney, J. Davis, and P. C. Kepple, JQSRT **57**, 41 (1997).
2. J. S. Levine *et al.,* Phys. Plasmas **8**, 533 (2001).
3. K. L. Wong *et al.,* Phys. Rev. Lett. **80**, 2334 (1998).

Since Z2603's implosion velocity changes little between -5 and -1 ns, it is reasonable to infer its diameter (2.71 mm) at -2.42 ns by interpolation. This is the time of the K-shell minimum between K-shell power peaks.

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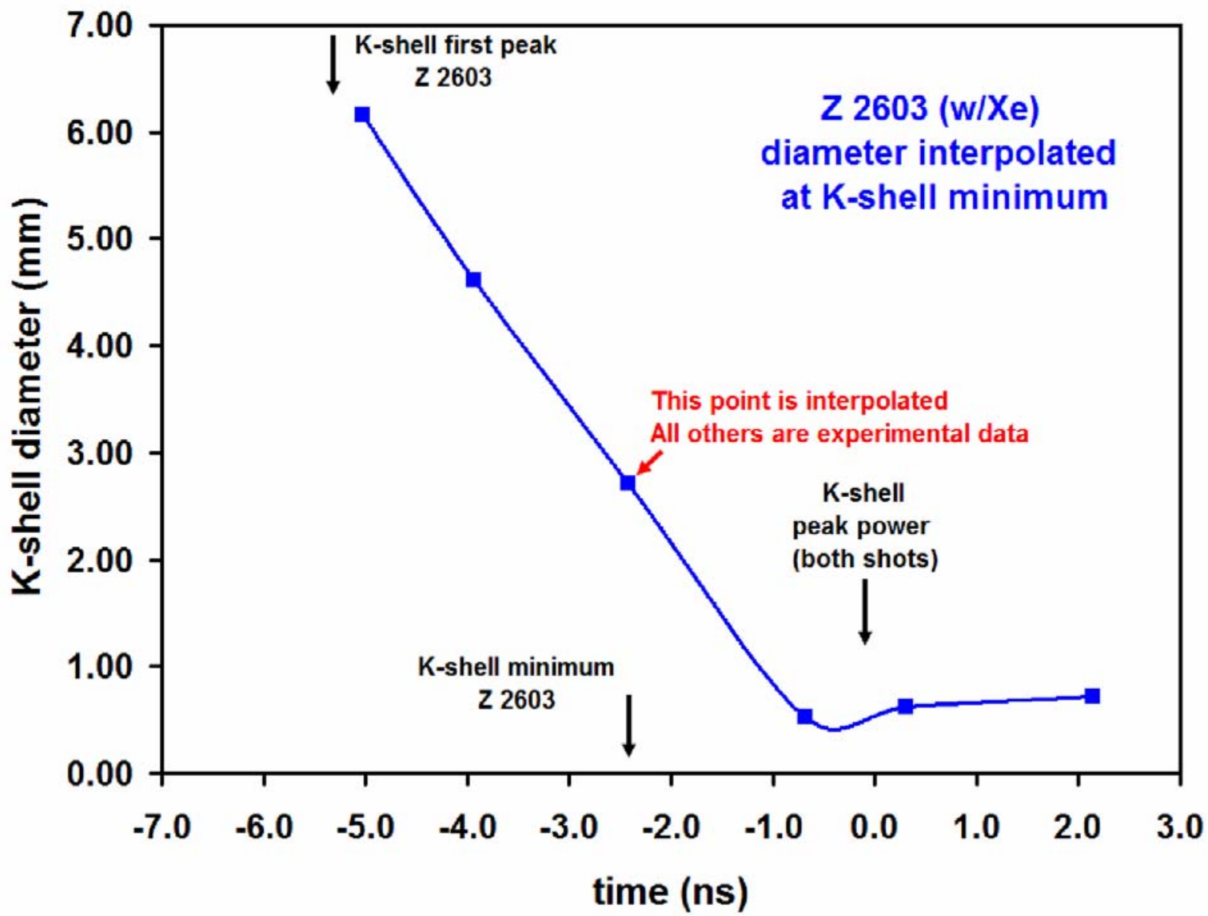

This interpolated diameter was used, along with the other data, to infer conditions at the K-shell minimum.

On the basis of the measured and interpolated diameters, line ratios, powers, and (known) mass load, temperatures and densities for the K-shell emitting region of the pinch can be derived.

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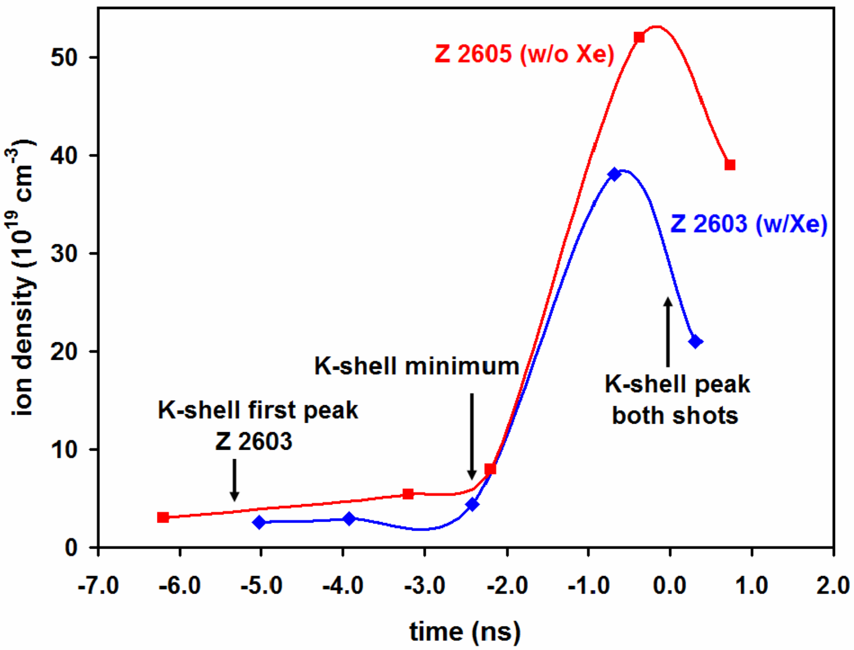
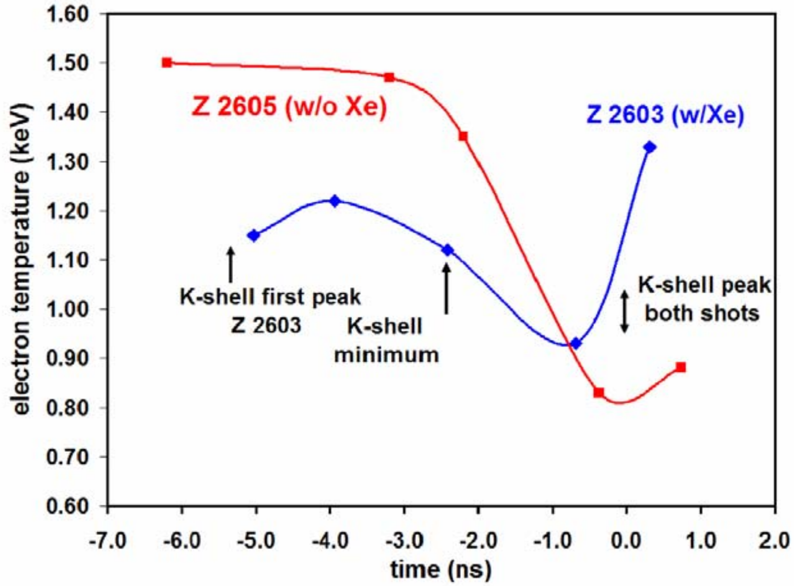
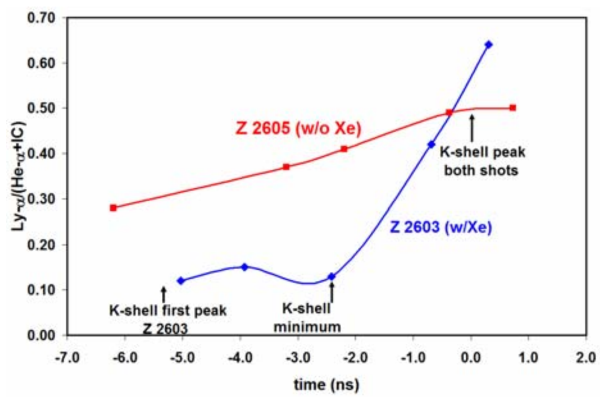
ion densities vs. time



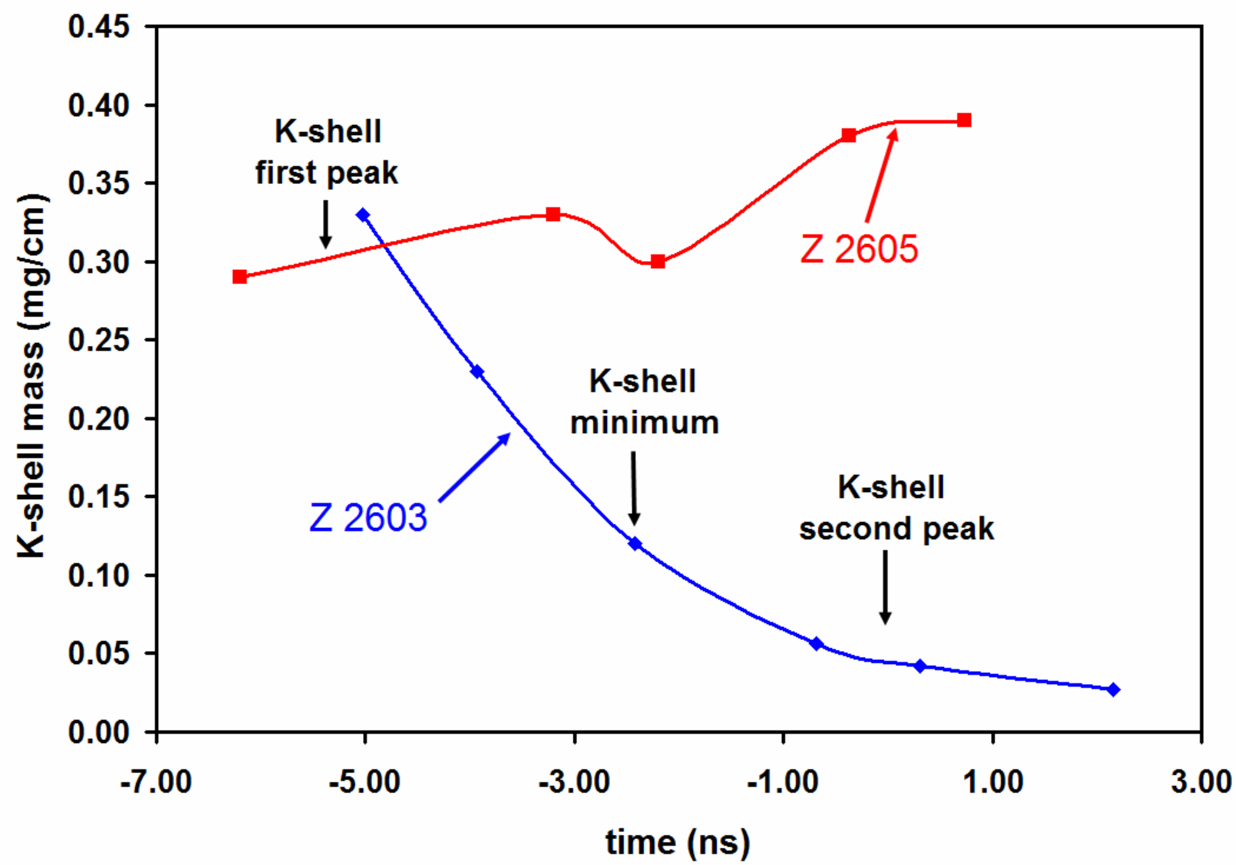


electron temperatures vs. time

line ratios



The most striking difference in the inferred data is the contrast in the derived K-shell radiating mass evolution during the implosion.



Model fit to K-shell power shows how it varies with pinch volume, temperature, and density

$$P_K\,(\mathrm{TW/cm})\ (\pm 13\%) = 0.37\ V^{0.85}(\mathrm{mm}^3)\ [N_i(10^{19}\ \mathrm{cm}^{-3}]^{1.57} \times \exp[-2.3/T_e(\mathrm{keV})]$$

The optically thin radiative cooling coefficients of Post *et al.*[1] show Xe cooling is significant, even though Ar exceeds Xe in the center jet by a factor of 125 by number.

T_e (keV)	Ar coeff	Kr coeff	Xe coeff	Xe/(125 Ar)
0.5	1.2	22.	25	0.17
1.0	0.24	7.1	17	0.57
2.0	0.36	4.8	18	0.40

The cooling coefficients are expressed in units of 10^{-26} W cm^3
Opacity of Ar likely increases the relative effect of the Xe by reducing the net Ar emission.

1. D. F. Post *et al.,* At Data Nucl. Data Tables 20, 397 (1977).

Summary

- Doping the center jet of Ar gas-puff shot Z2603, with 0.8% Xe, reduced its K-shell yield and power by factors of 3-4 compared to an otherwise identical shot (Z2605). Z2603 also had two nearly equal K-shell power peaks. Radiative cooling by the Xe is the likely explanation.

- Time- and space-resolved x-ray data shows that Z 2603 imploded to a smaller K-shell diameter than did Z 2605. Collisional-radiative atomic and radiation transport modeling infers electron temperatures of 1-1.5 keV and K-shell ion densities of 2-50 x 10^{19} cm^{-3}. The smaller diameter is due to a smaller ionized region, not greater compression.

- The most notable difference in the inferred properties is the K-shell radiating mass. Z 2603's K-shell mass declines during the implosion as the radiative cooling due to Xe increases with density. The K-shell mass of Z 2605 is fairly stable at about 30% of the total load, similar to that from other successful shots.

- The initial drop in the K-shell mass for Z 2603 may be responsible for the K-shell minimum. As the electron temperature increases near stagnation, a second peak in K-shell power occurs. The double peak is due to the interplay of temperature, density, and volume as expressed in a model fit to the measured K-shell power.

Note on line ratio temperature dependence

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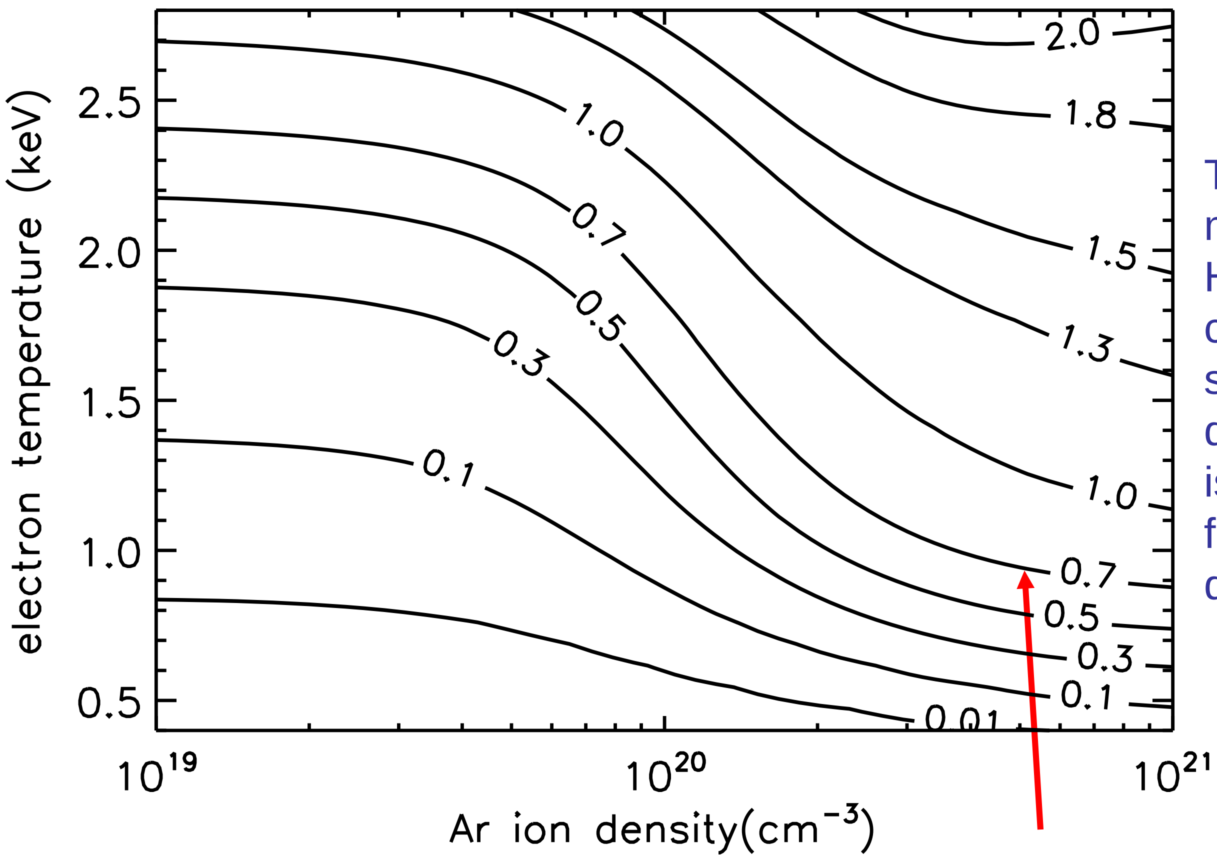

The line ratio Ly-α/(He-α+IC) is mostly temperature-dependent. However, ionization from collisionally-populated excited states introduces some density dependence. Below are isocontours of this ratio for a cylindrical Ar plasma of diameter 3.0 mm.

At higher density, a given Ly-α/(He-α+IC) ratio is attained at lower temperatures