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Domination of the K-radiation at a z-pinch stagnation on Z by numerous tiny spots and the properties of the spots inferred by experimental determination of the K-line opacities

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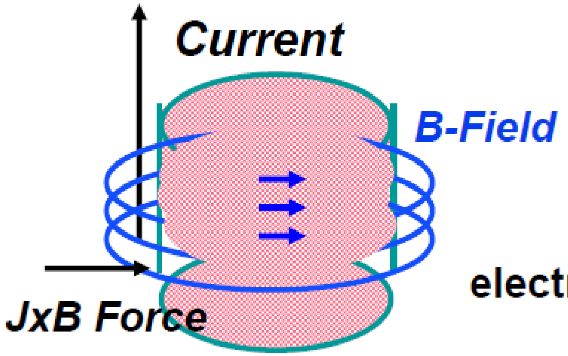
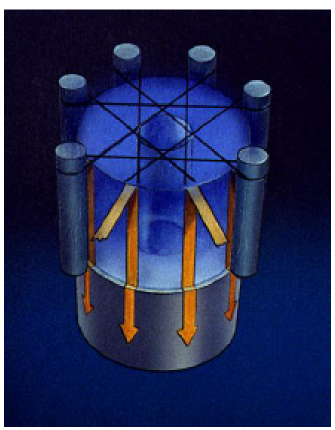
Magnetically-driven fast Z-pinch implosions efficiently convert electrical energy into radiation

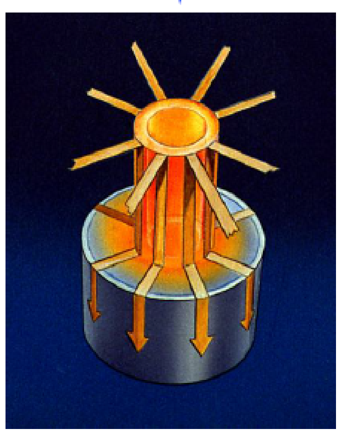


kinetic and magnetic energy
↓
internal energy
↓
x rays

electrical energy
↓
kinetic energy



Ablation



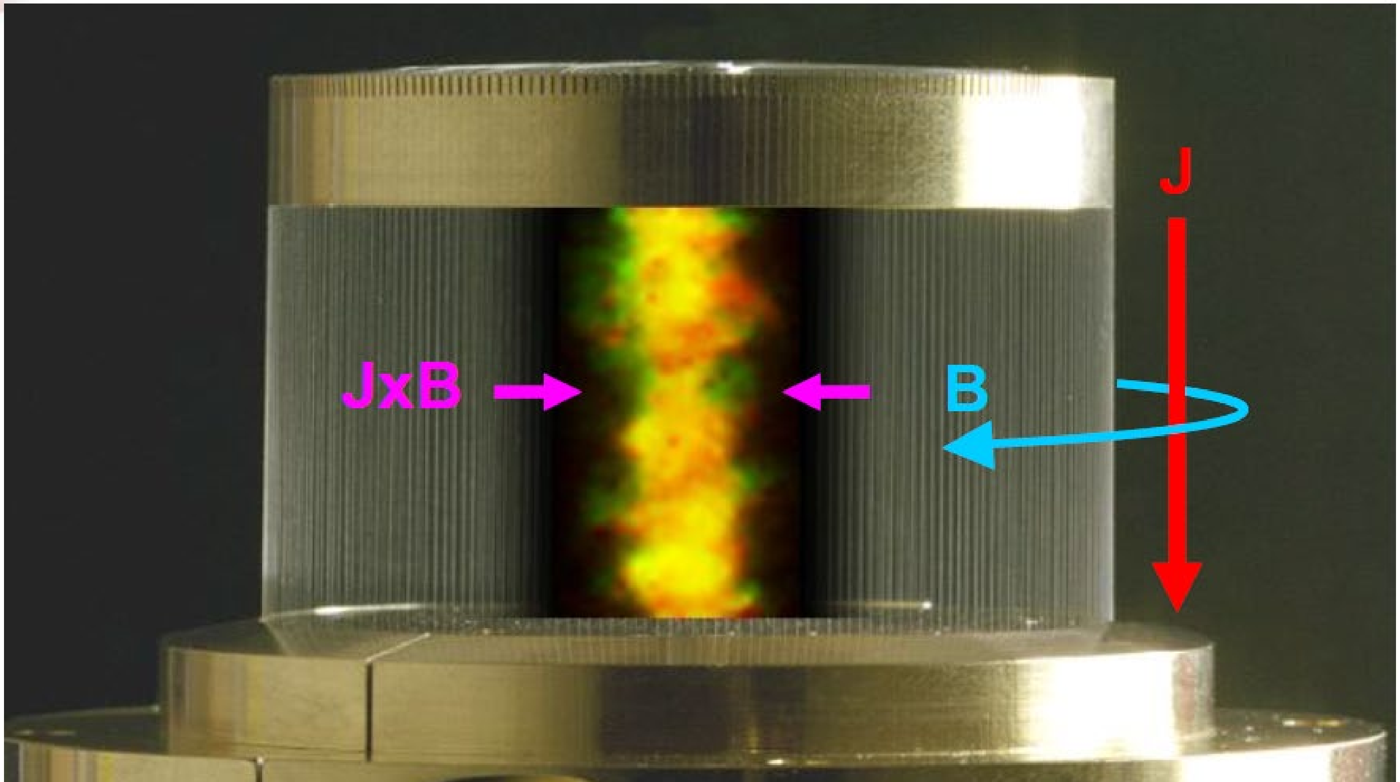
Implosion

Stagnation

Fast wire z-pinch loads:

- Z-pinches are imploded in 60 to 120 ns
- Energy: x-ray ≈ 15% of stored electrical

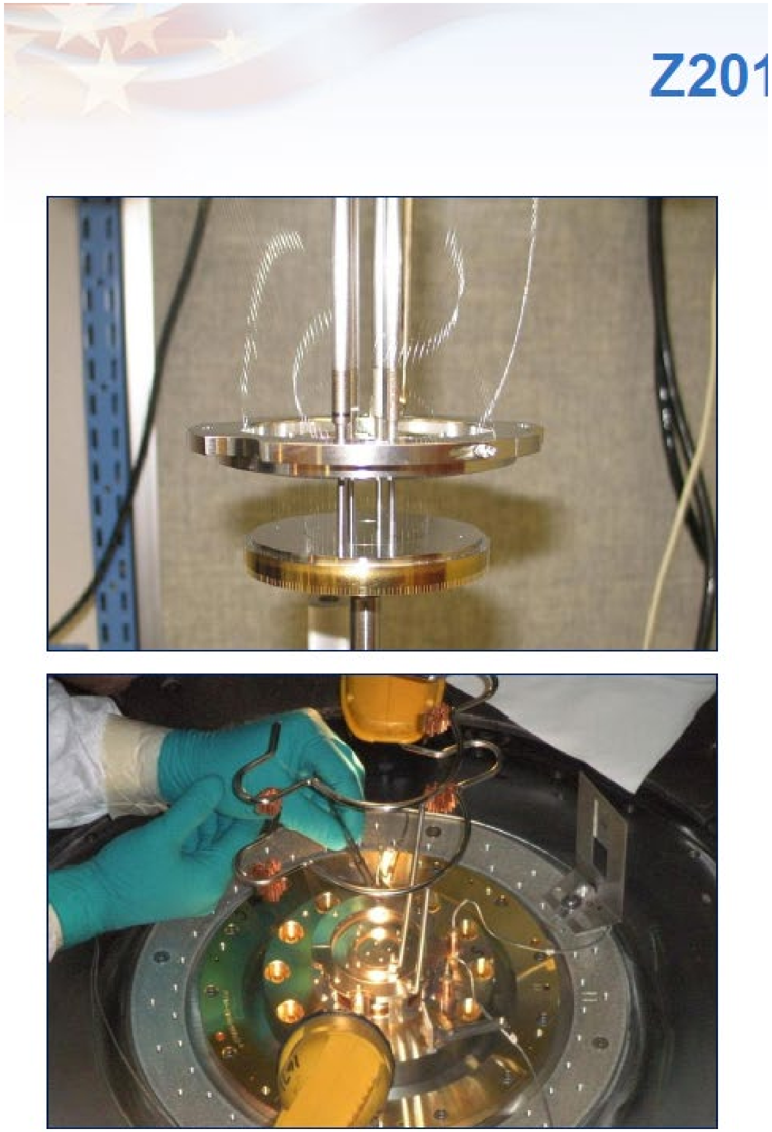
J x B force pinches wire array into a dense, radiating plasma column



z-pinch sources

$Y_{rad} \sim 1 - 2$ MJ

$P_{rad} \sim 100 - 250$ TW



Shot Z2011 on Z

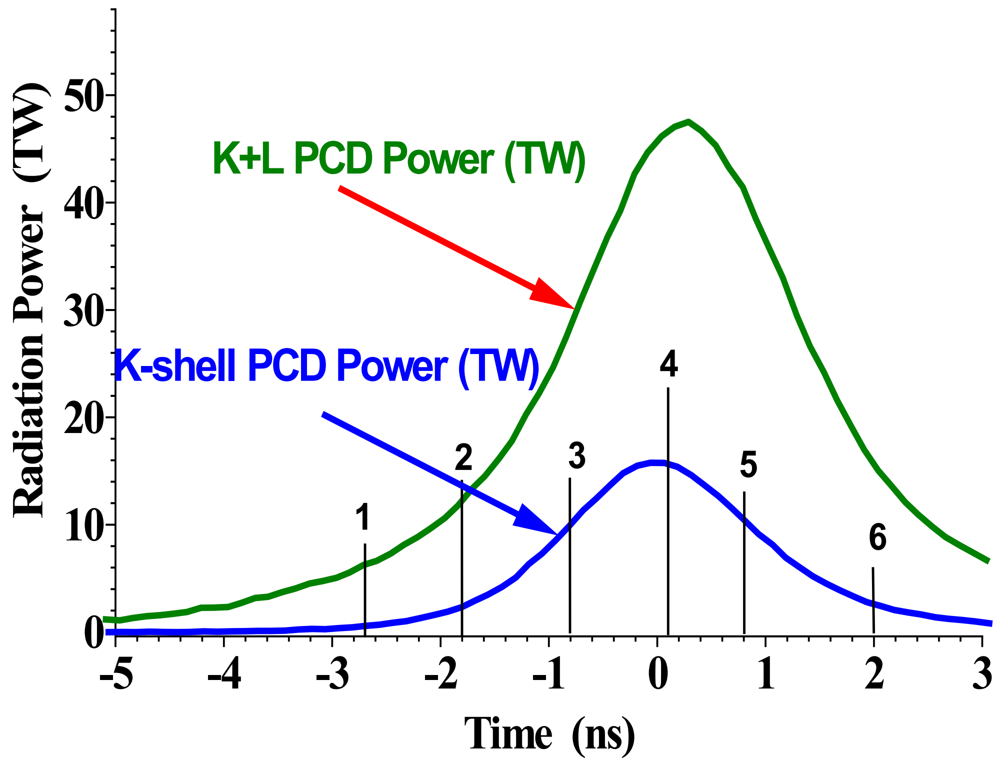
Stainless steel
(Fe, Cr, Ni, Mn)

Length 2 cm
Radius of stagnation 1 mm.

Dave Ampleford et al PoP 2013

Spectra of Fe, Cr, Ni, and Mn K-lines are recorded each 0.8 ns

The peak K-emission power is at t = -1 ns to t = 1 ns.



K + L is filtered for > 700 eV

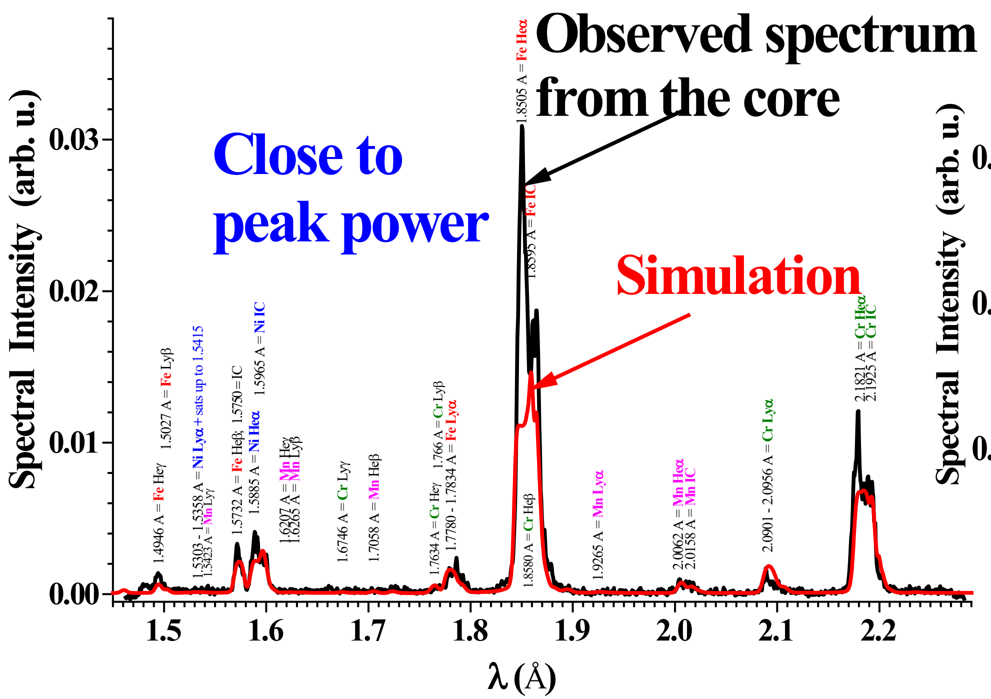
K is filtered for > 3 keV ;

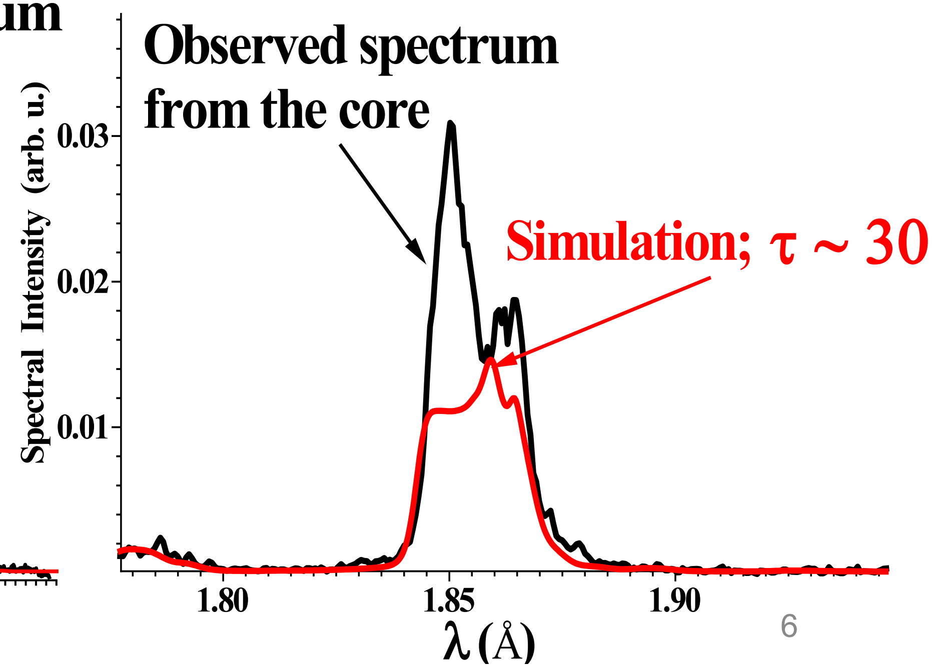
Dave Ampleford et al PoP 2013

Spectra are commonly simulated using uniform-cylinders for the pinch stagnation

Such simulations give opacities $\tau \sim 30$ for Fe He_{α}, which somewhat fits the spectra very early at stagnation

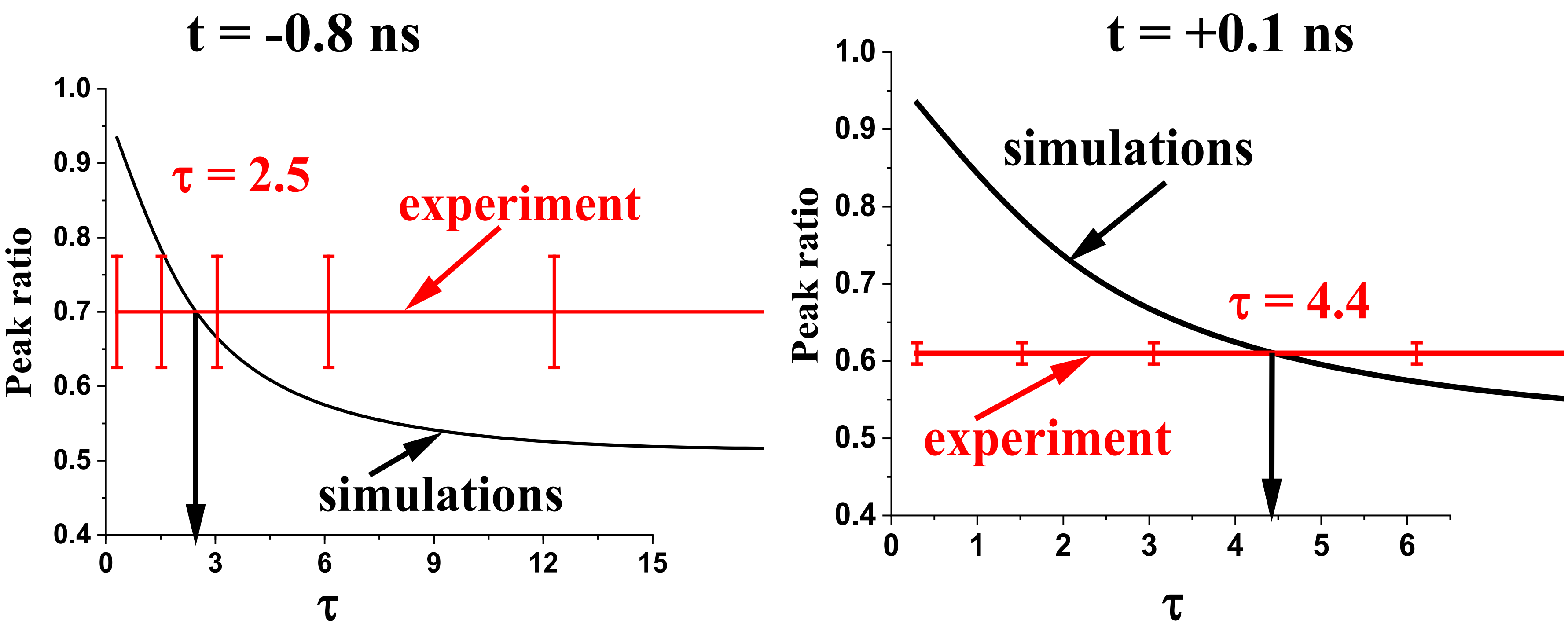
However, at peak power the apparent τ of Fe He_{α} is much smaller.





We utilized the different abundances of Fe, Ni, Cr, and Mn to determine the resonant-line opacities

Fe He$_{\alpha}$ to Mn He$_{\alpha}$ peak-intensity ratio as a function of τ give τ ≤ 5 « 30 (uniform cylinder)

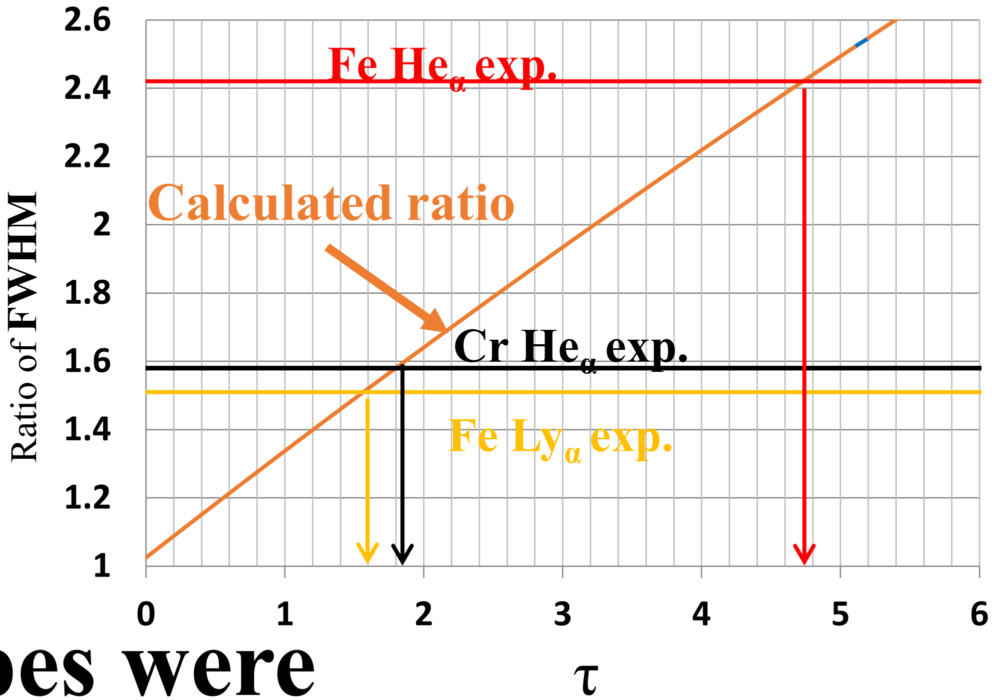


Determination of τ from the ratio of the FWHM of Fe He$_\alpha$, Fe Ly$_\alpha$, and Cr He$_\alpha$, to the FWHM of Mn He$_\alpha$ for peak power

The treatment of FWHM data includes:

1. De-convolution of the instrumental broadening.
2. Determination of Doppler broadening for each element.

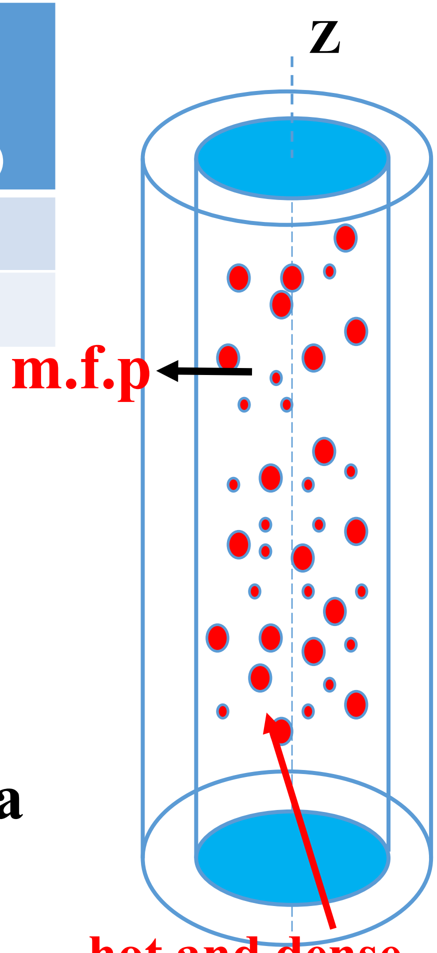
All lines of the various species were shown to have consistent opacities



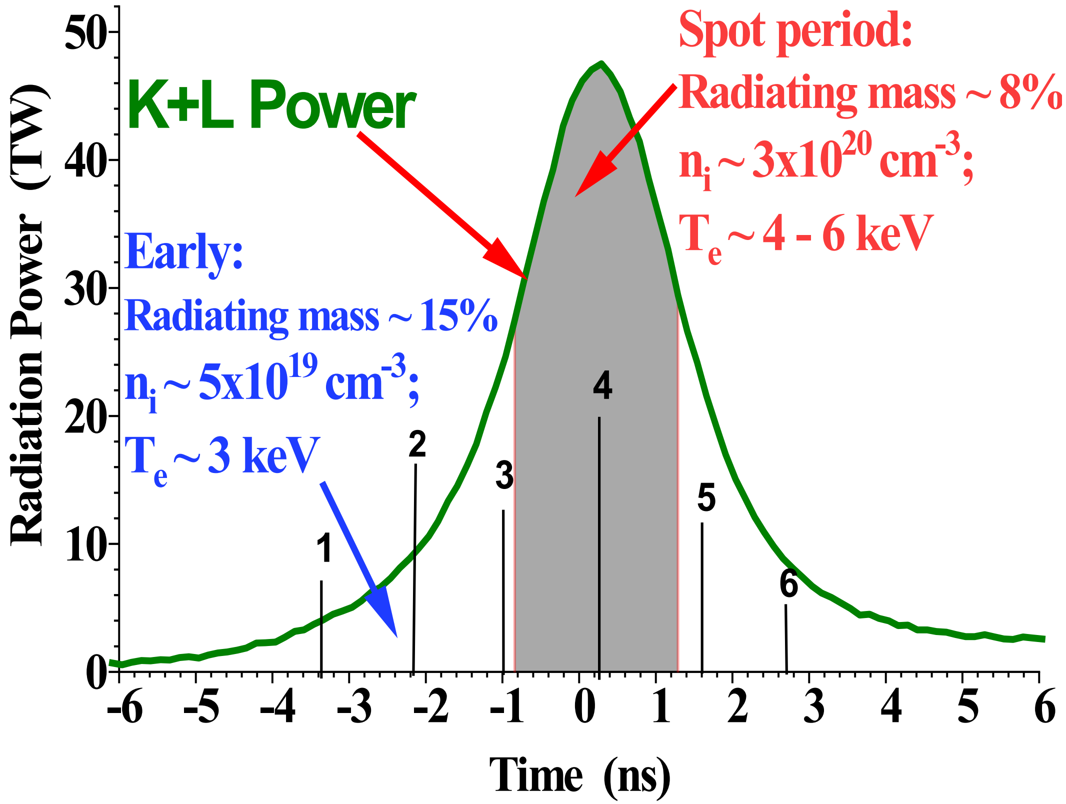
Various line shapes were tried, all giving for Fe He$_\alpha$ $\tau \leq 5 \ll 30$

The only way seen for explaining this finding is the Multi-Spot Picture

t (ns)	Small structure Diameter	n_i (sm^{-3})	T_e (eV)	Number of spots	Mass (% of M_W)	V_s (% of volume)
-0.8	100 µ	$3x10^{20}$	4000	4300	7	9
+0.1	100 µ	$4x10^{20}$	6000	4500	9	9



- The emission is from bright spots.
- The ion density n_i is high; the radiation is ~ n_i^2
- The number of spots needs to be large in order to provide the entire emission.
- m.f.p - mean free path of the photons in the spot region must be larger than the radius of the plasma column (> 1 mm).
- The spots can be smaller , but not much larger.
- Te determined separately .



n_i and T_e in the spots are higher than earlier

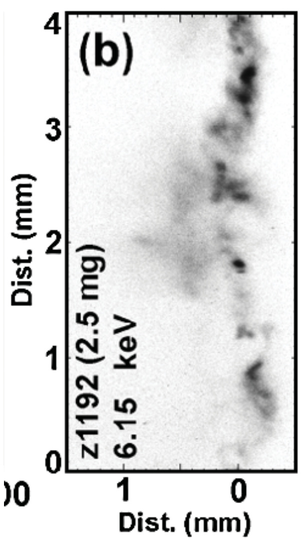
Remarkably:

When the power rises ~ 4x to its peak , the mass of the radiating plasma is twice less than at earlier times

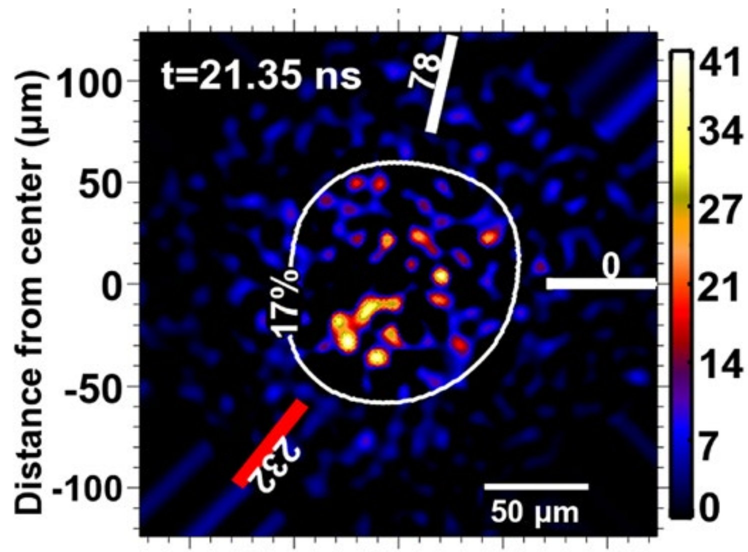
The life time of the spots is shorter than stagnation , thus they must be continuously replaced by others, or must be continuously heated up by an energy source.

Difficult to observe a large number of spots by the chord- integrating imaging, in particular if time-integrated

Sinars et al. PRL 2008 , time integrated high-spatial-resolution imaging. Example time-integrated 6.15 keV emission image from a tungsten wire array at Z. (20 μ resolution)



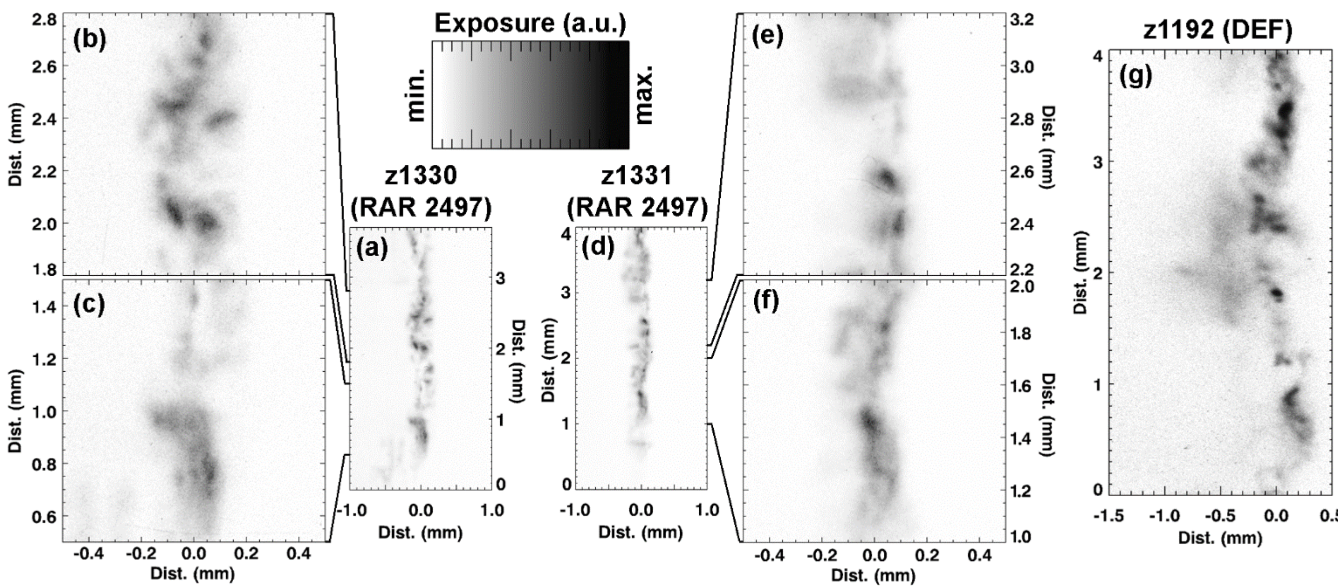
Small structures have seen in NIF (Barrios, et al. PoP 2013). The size of the spot s is 10 μ or less.



- Alexander Velikovich et al. Session MO 4.3-6 ICOPS 2022

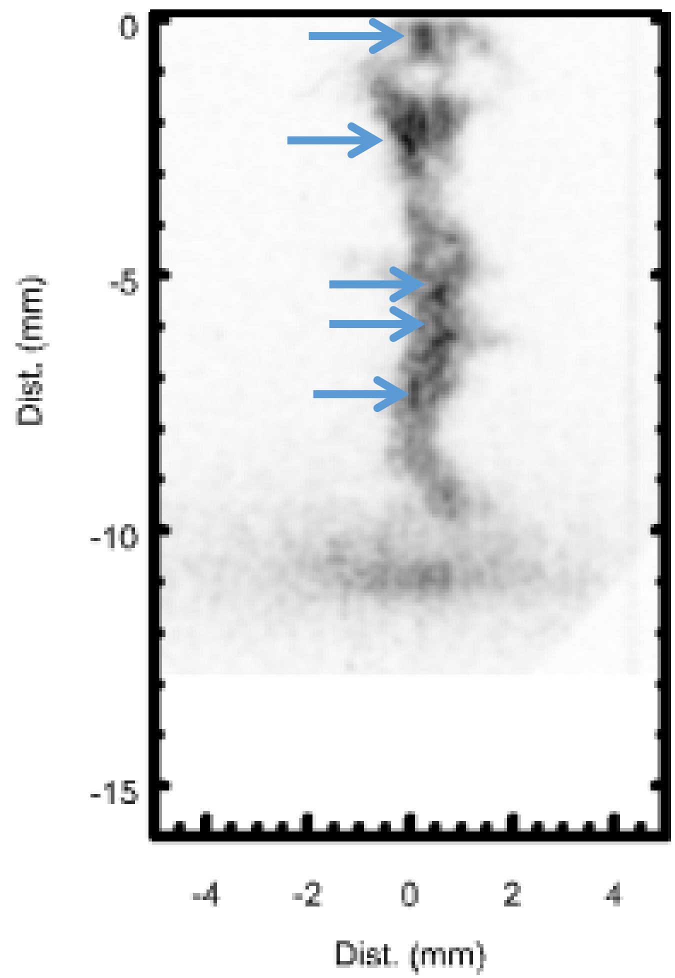
Inference of radiation from spots on considerations on the continuum radiation.

Dan Sinars et al , PRL (2008) and unpublished data .



Images of the experiment where spectroscopy indicated spots shows a structured stagnation column

- Self-emission imaging of K-shell emission at peak x-rays shows bright spots for the same experiment where spectroscopy indicated spots (z2011)
- Instrument resolution is few 100µm so resolution limited on some of these structures



Summary

A quantitative analysis, based on the experimental line opacities, demonstrates the existence of the spots at peak stagnation, as well were determined their number, size, ion density, electron temperature, and time evolution.

Questions raised:

- What is the process that causes the apparent transition from a "nested cylinder" plasma to a discretized set of "bright spots"?
- What causes the spots to be either continuously replaced or being continuously heated up?
- How general these findings are ?
- Can modeling be developed to explain this phenomenon?

Thank you for your attention