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U.S. NAVAL RESEARCH LABORATORY

1-D MHD simulation of an argon gas puff implosion with time-dependent non-LTE kinetics*

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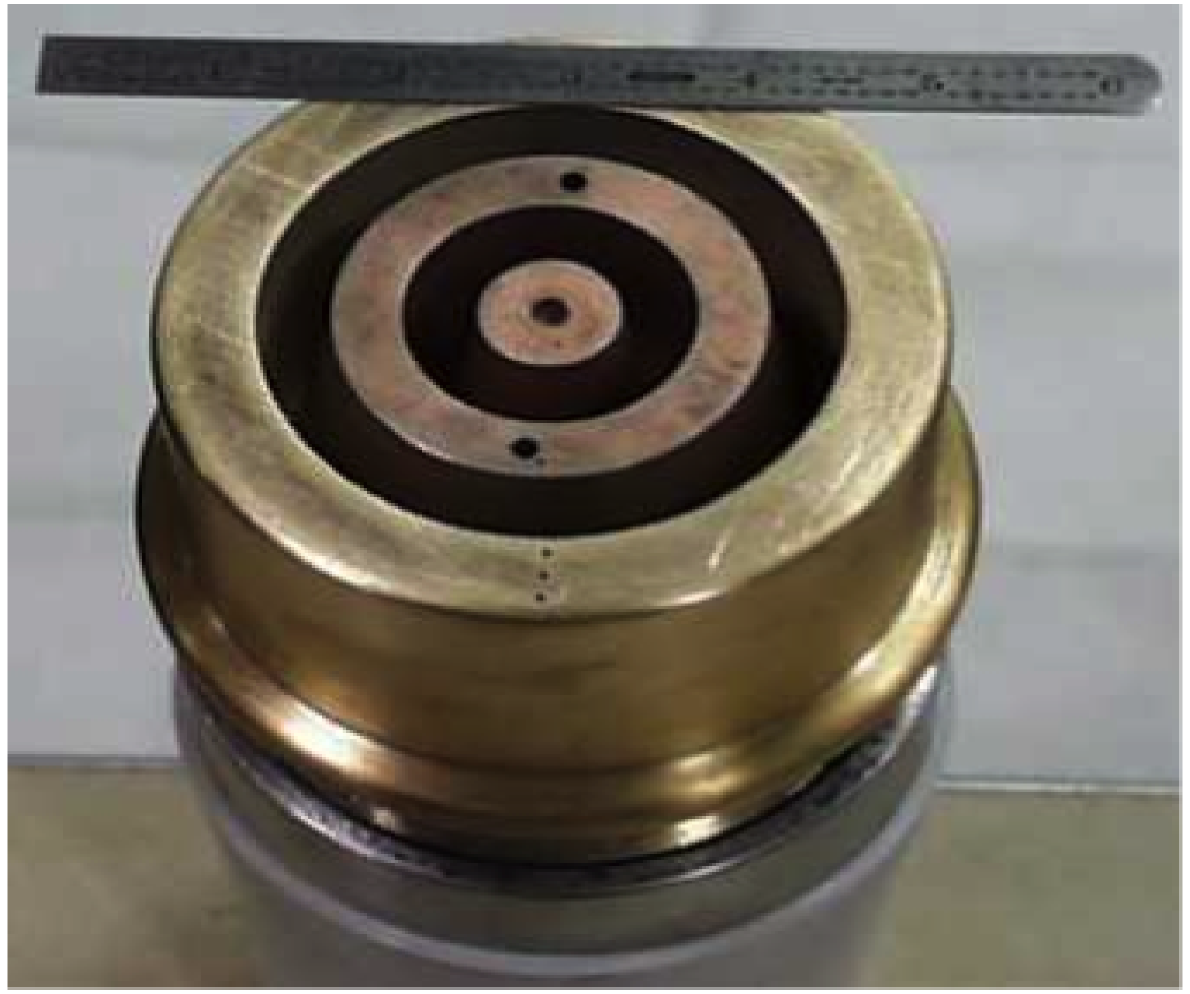
Summary and Future Work

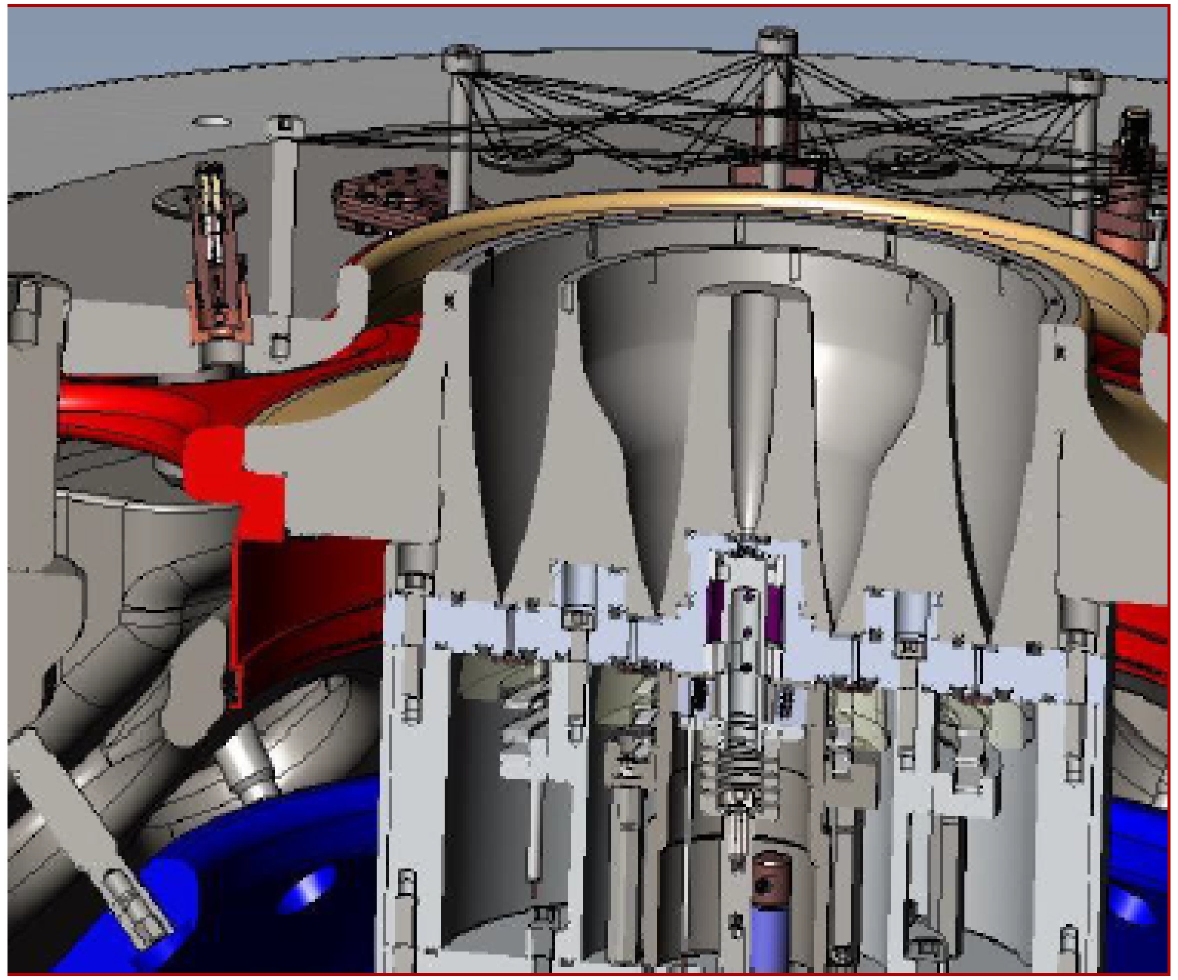
NRL PPD

- Argon gas puff experiments on the Z machine have produced 330 kJ ± 9% above 3 keV photon energies
- Simulations using Mach2-TCRE were able to reproduce the radiative powers and yield from shot Z2560
  - The Mach2-TCRE simulation's Ly-α/He-α+IC line ratio had good agreement after peak power, but was higher prior to peak power. This was attributed to 3-D effects and the implicit assumption of steady-state populations in the TCRE table.
- The 1-D NRL DZAPP code was used to assess the effects of time-dependent ground state level populations compared to steady-state for the Ly-α/He-α+IC line ratio
  - There was a decrease in the line ratio in the case of the time-dependent ground state level populations
  - However, the line ratio was still larger compared with experiment.
  - Time-dependent level kinetics and multi-dimensional effects may both be important.
- Future work will assess the effects of time-dependent level kinetics for NGPP loads

Argon gas puff experiments on the Z machine have produced 330 kJ ± 9% above 3 keV photon energies

NRL PPD





An 8 cm diameter double-shell gas nozzle was used.
The mass of the argon gas was 1 mg/cm.
The inner- to outer-shell mass ratio was 1.6:1.
The length was 2.5 cm.

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B. Jones *et al*. Physics of Plasmas 22, 020706 (2015)

Simulations using Mach2-TCRE were able to reproduce the radiative powers and yield from shot Z2560

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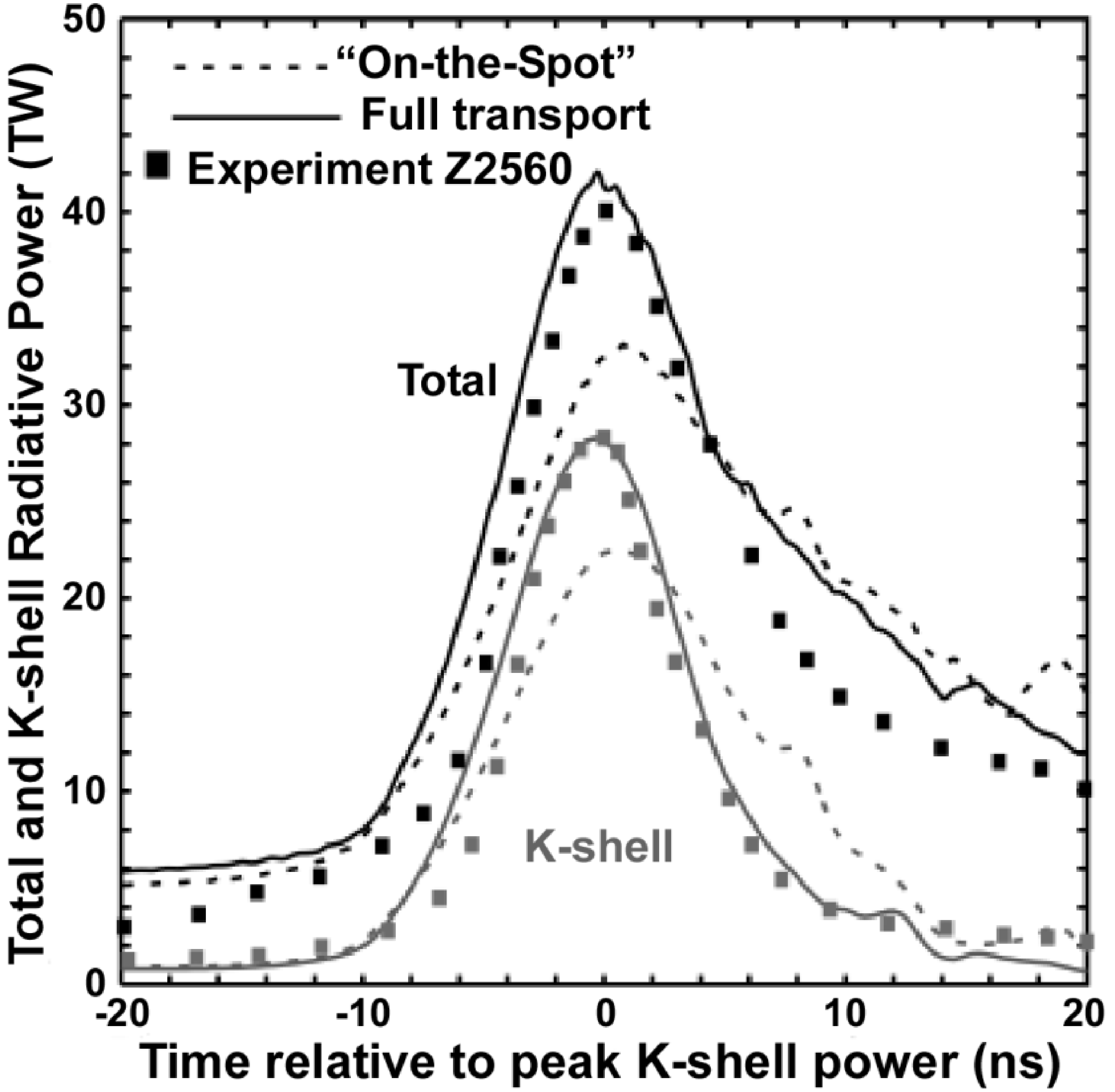
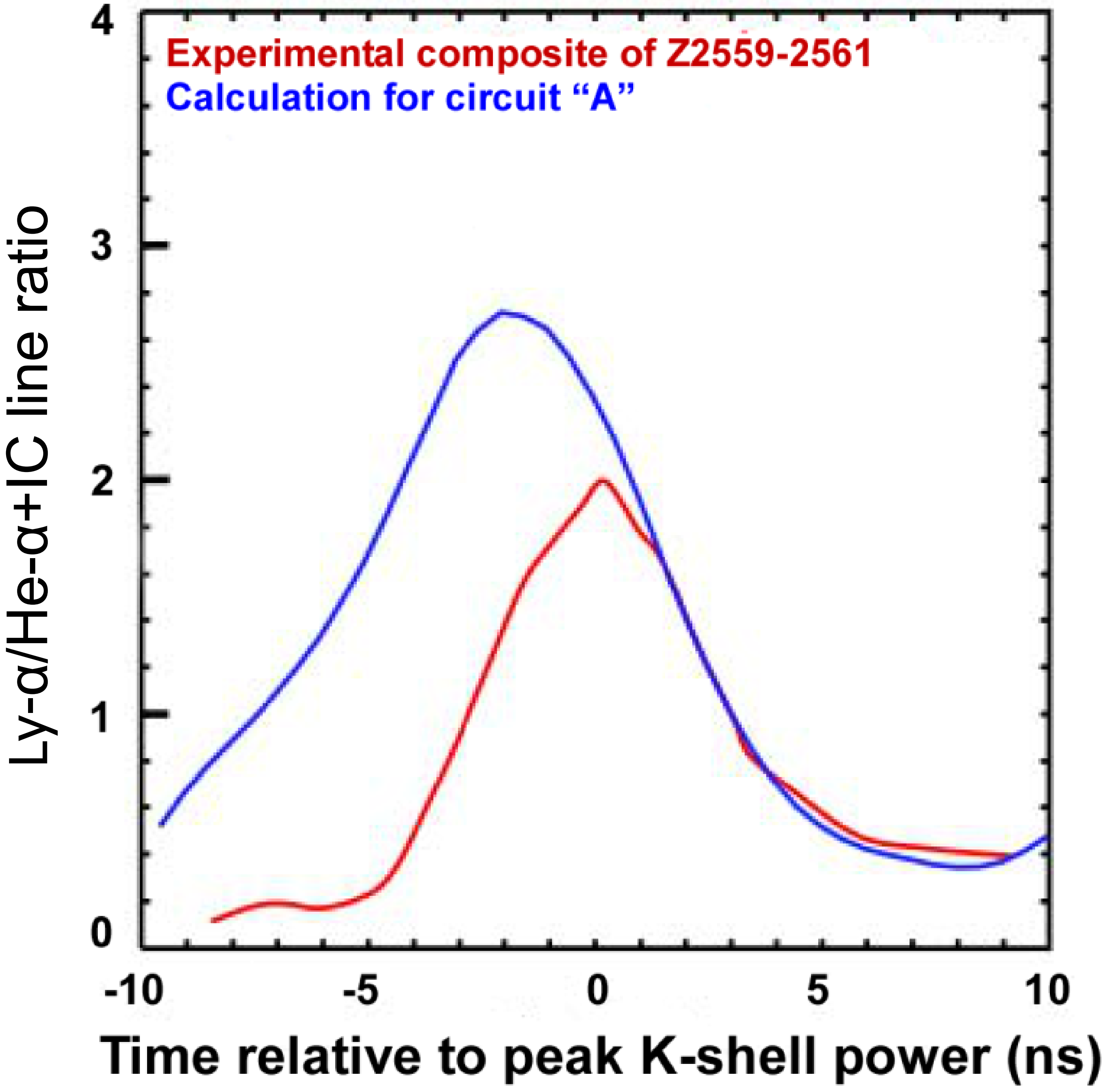


J.W. Thornhill *et al.* IEEE TPS 43, 2480 (2015)

The simulation's Ly-α/He-α+IC line ratio had good agreement after peak power, but was higher prior to peak power.

NRL PPD



Label	Upper	Lower	Energy
IC	$1s2p\ ^3P_1$	$1s^2\ ^1S_0$	3.124 keV
He-α	$1s2p\ ^1P_1$	$1s^2\ ^1S_0$	3.140 keV
Ly-α_2	$2p\ ^2P_{1/2}$	$1s\ ^2S_{1/2}$	3.318 keV
Ly-α_1	$2p\ ^2P_{3/2}$	$1s\ ^2S_{1/2}$	3.323 keV

Thornhill *et al.* attributed this discrepancy prior to peak power to:

1. 3-D effects
2. Implicit assumption of steady-state populations in the TCRE table.

This presentation will explore the effect of time-dependent level population kinetics on the line ratio.

J.W. Thornhill *et al.* IEEE TPS 43, 2480 (2015)

The NRL DZAPP code was used to assess the effect of time-dependent and steady-state atomic level kinetics

NRL PPD

DZAPP is a coupled 1-D MHD, detailed non-LTE atomic physics with radiation transport, incorporating a transmission line circuit for the driving generator.

The non-LTE population dynamics and radiation transport are time-split from the MHD.

For steady-state populations the time derivative is set to zero

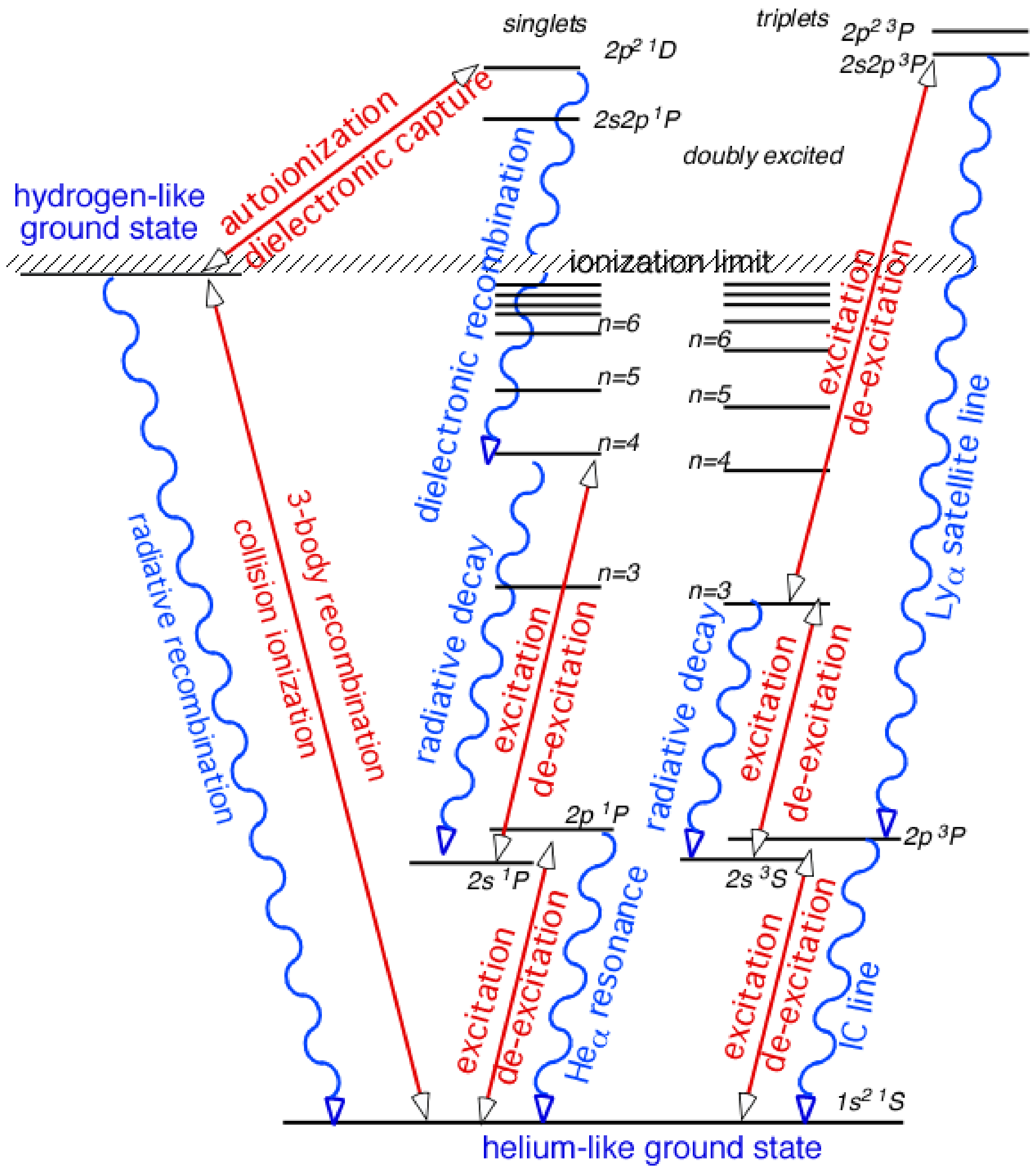
Population of atomic level i in spatial zone k

$$\frac{\mathrm{d}f_{ik}}{\mathrm{d}t} = \sum_j \left(W_{jik} f_{jk} - W_{ijk} f_{ik}\right)$$

Net rate describing a transitions from atomic level j to atomic level i

All physical processes in our collisional-radiative modeling are driven by non-LTE atomic kinetics

NRL PPD



Spontaneous decay/Resonant photoabsorption

$$X_j^{Z*} \Leftrightarrow X_i^Z + h\nu$$

Electron impact ionization/3-body recombination

$$X_i^Z + e \Leftrightarrow X_j^{Z+1} + e' + e''$$

Electron impact excitation/deexcitation

$$X_i^Z + e \Leftrightarrow X_j^{Z*} + e'$$

Photoionization/radiative recombination

$$X_i^Z + h\nu \Leftrightarrow X_j^{Z+1} + e$$

Autoionization/resonant capture

$$X_i^{Z+1} + e \rightarrow X_j^{Z**}$$

Bremsstrahlung/inverse bremsstrahlung

$$X_i^Z + e \rightarrow X_i^Z + e + h\nu$$

Dielectronic recombination

$$X_i^{Z+1} + e \rightarrow X_j^{Z**}$$

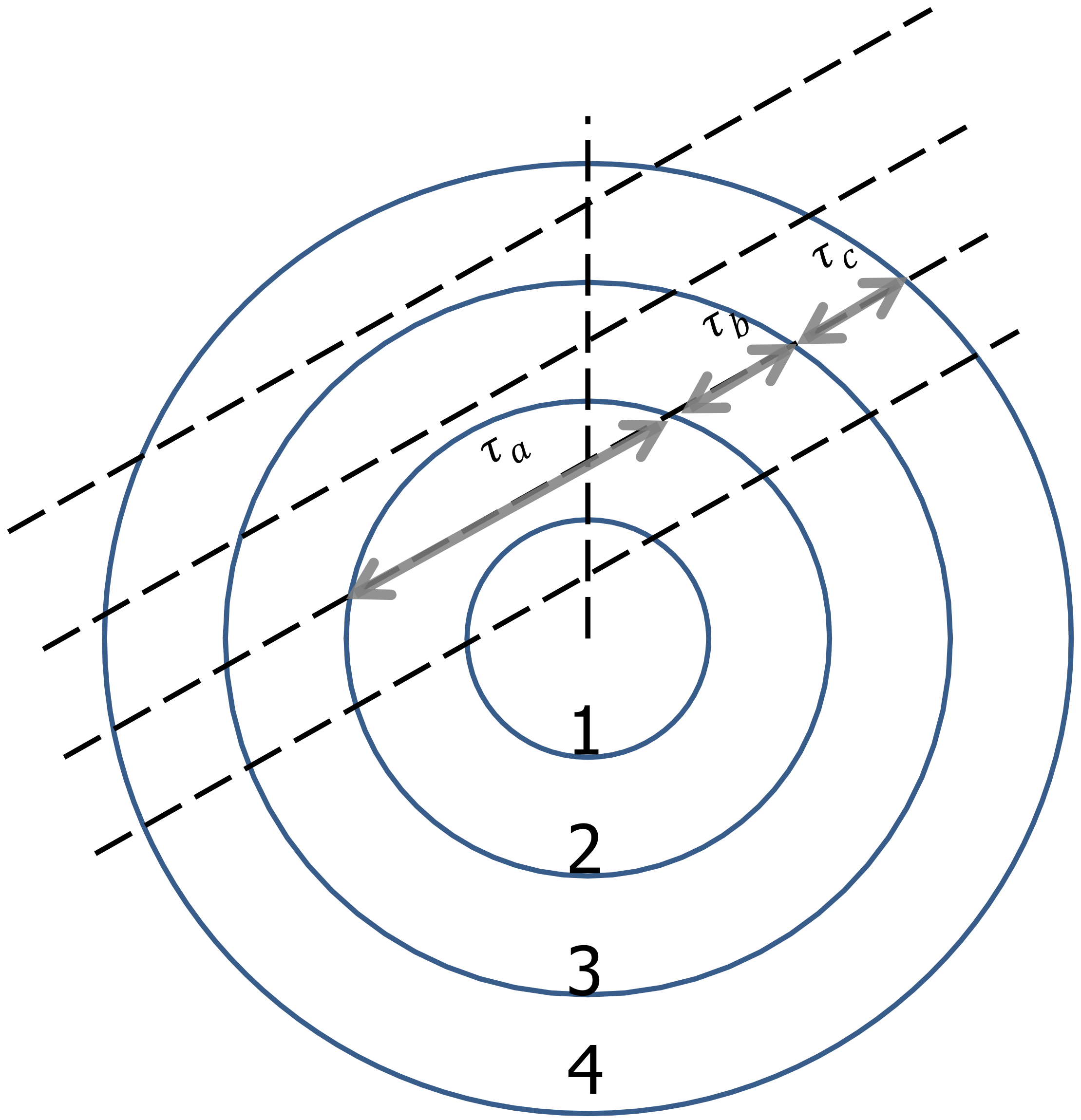
$X_j^{Z**} \rightarrow X_i^Z + h\nu$ and/or $X_j^{Z**} \rightarrow X_i^{Z+1} + e$

The populations depend on the rates of these atomic processes and can be determined by:

$$\frac{df_{ik}}{dt} = \sum_j \left(W_{jik} f_{jk} - W_{ijk} f_{ik}\right)$$ + photo-pumping by non-local radiation field

Multi-zone radiation transport via the coupling constant formulism provides good overall energetics at a reasonable cost in computer time

NRL PPD



Multi-zone radiation transport is necessary because photons are more likely to escape near the edge

$$C_{24} = \frac{1}{\tau_a}\int_0^{\tau_a} [P_e(\tau_b + \tau) - P_e(\tau_b + \tau_c + \tau)]\, d\tau$$

Reciprocity relation:

$$C_{42} = C_{24}\frac{N_2}{N_4}$$

Ratio of number of absorbers

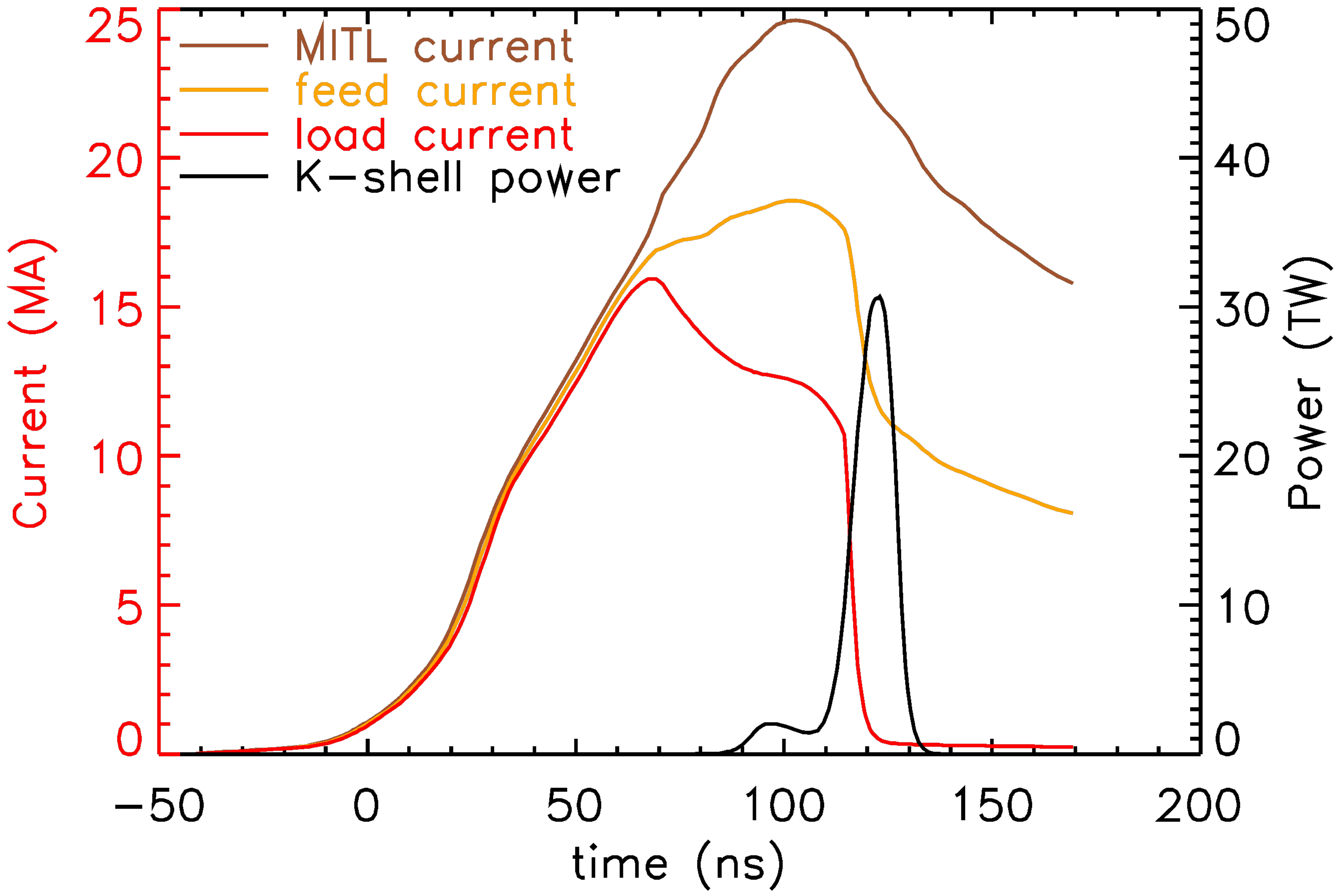
The photo-excitation rate for transition *i'–i* in spatial zone *k*:

$$\mathrm{W_{ii'k}} = 4\pi \sum_{k'\neq k} C_{k'k}^{ii'} j_{k'}^{ii'} \frac{V_{k'}}{N_k f_{ik} E_{ii'} V_k}$$

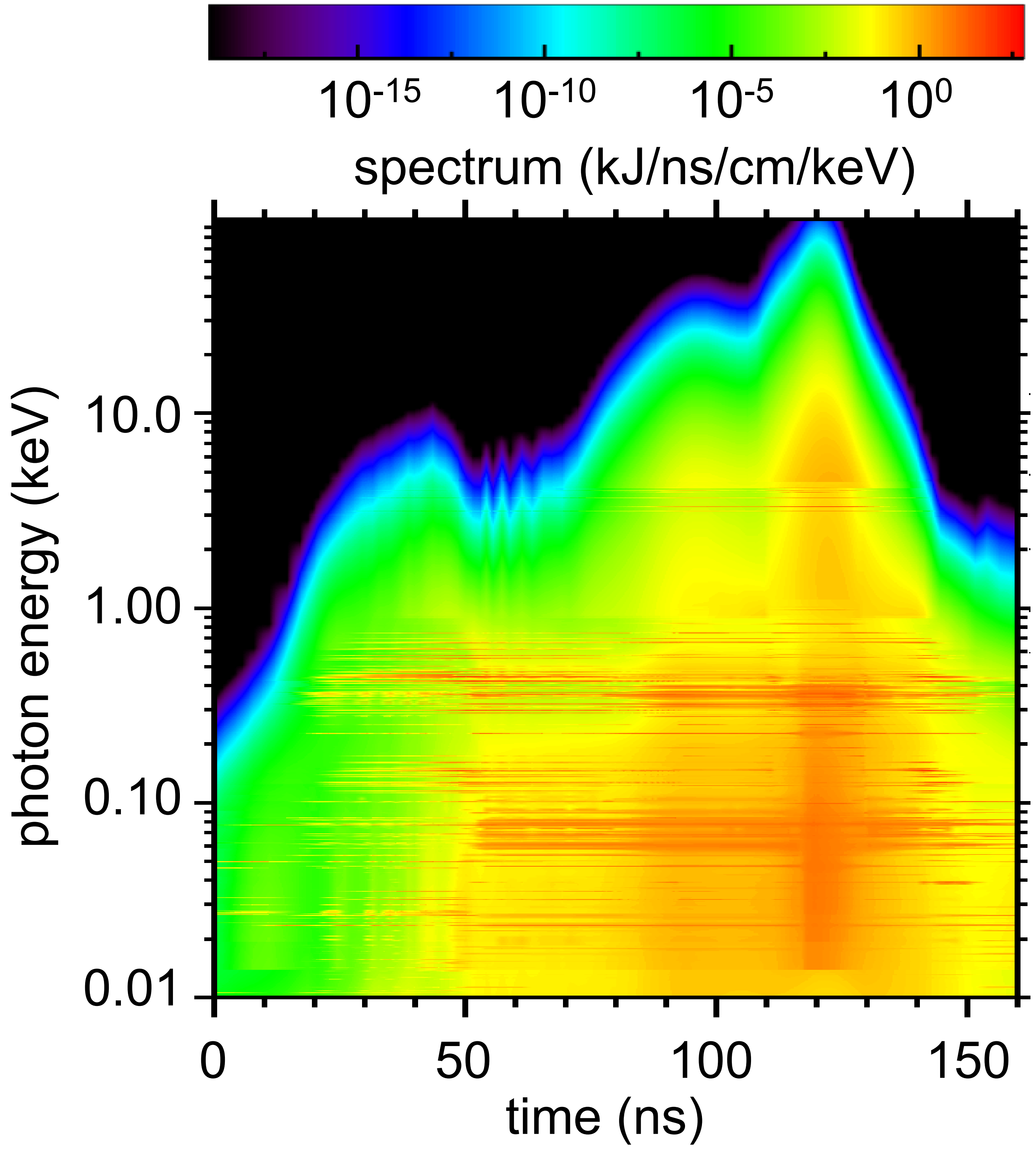
J.P. Apruzese *et al*. JQSRT 23, pp. 479-487 (1980)
J.P. Apruzese. JQSRT 25, pp. 419-425 (1981)
J.P. Apruzese. JQSRT 34, pp. 447-452 (1985)
R.W. Clark *et al*. JQSRT **53**, pp. 307-320 (1995)

Current waveforms, x-ray powers, and spectra assuming collisional-radiative steady-state level populations

NRL PPD

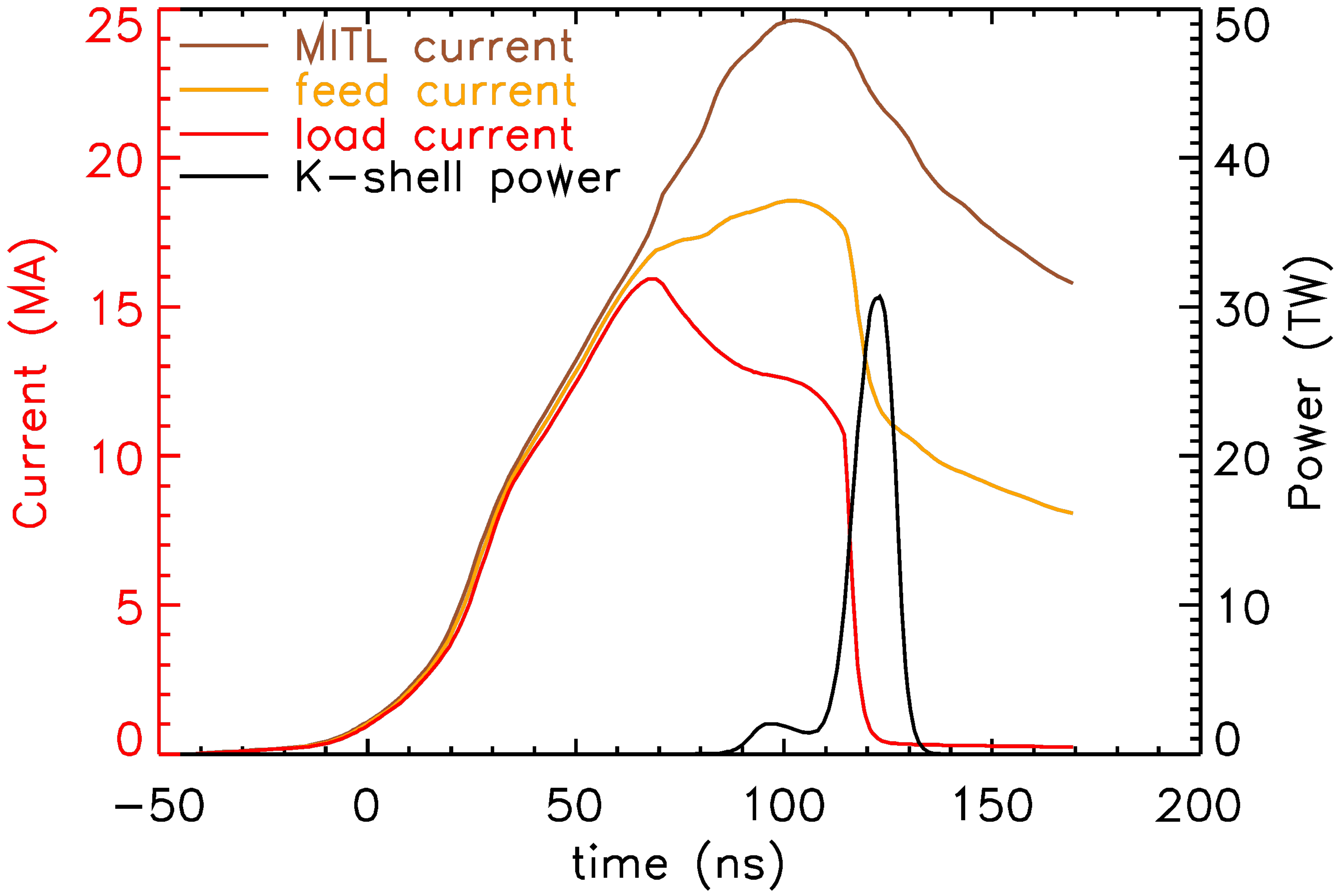


K-shell yield: 380 kJ



The plasma is too hot as determined from the Ly-α/He-α+IC line ratio (steady-state level populations)

NRL PPD



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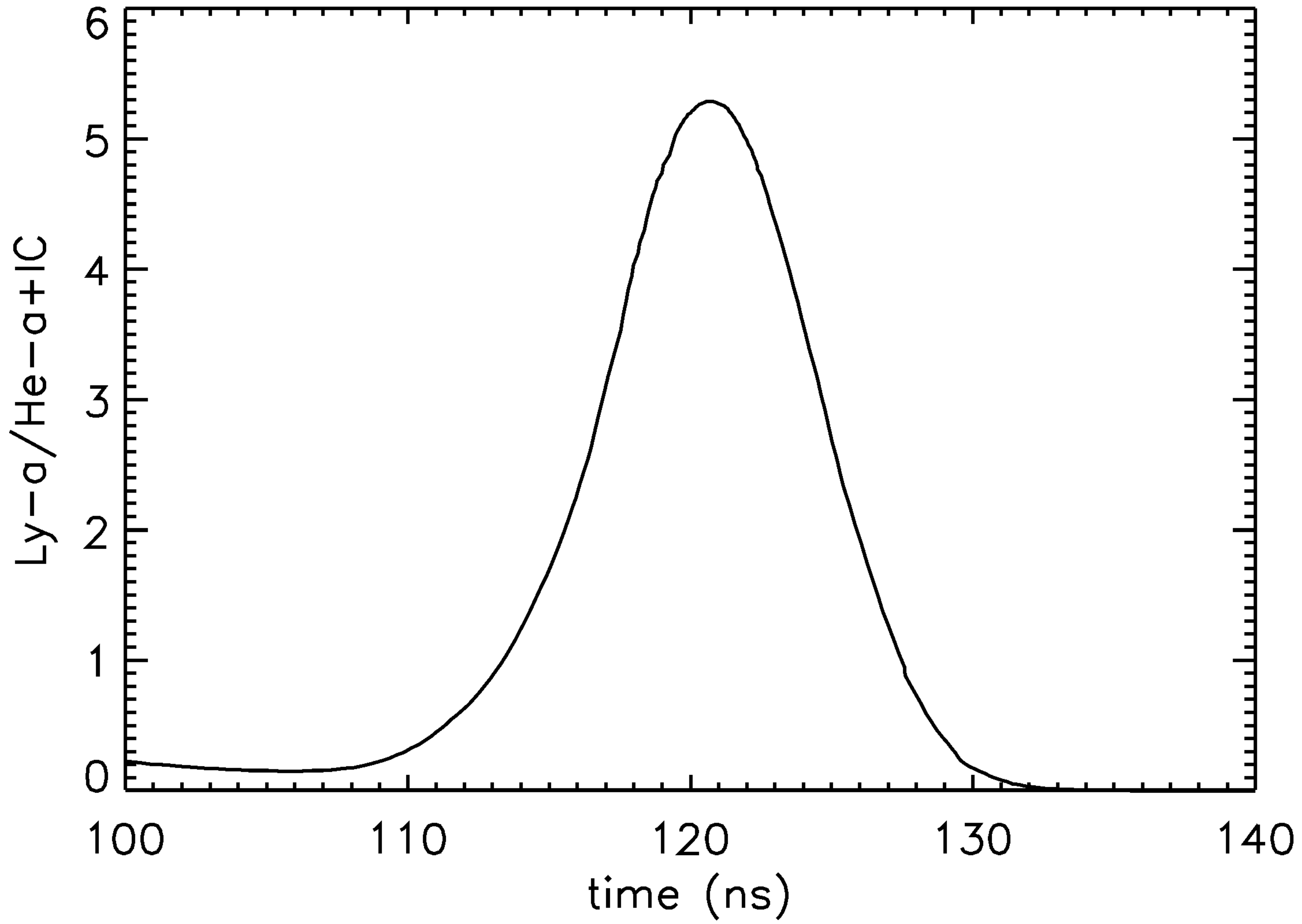

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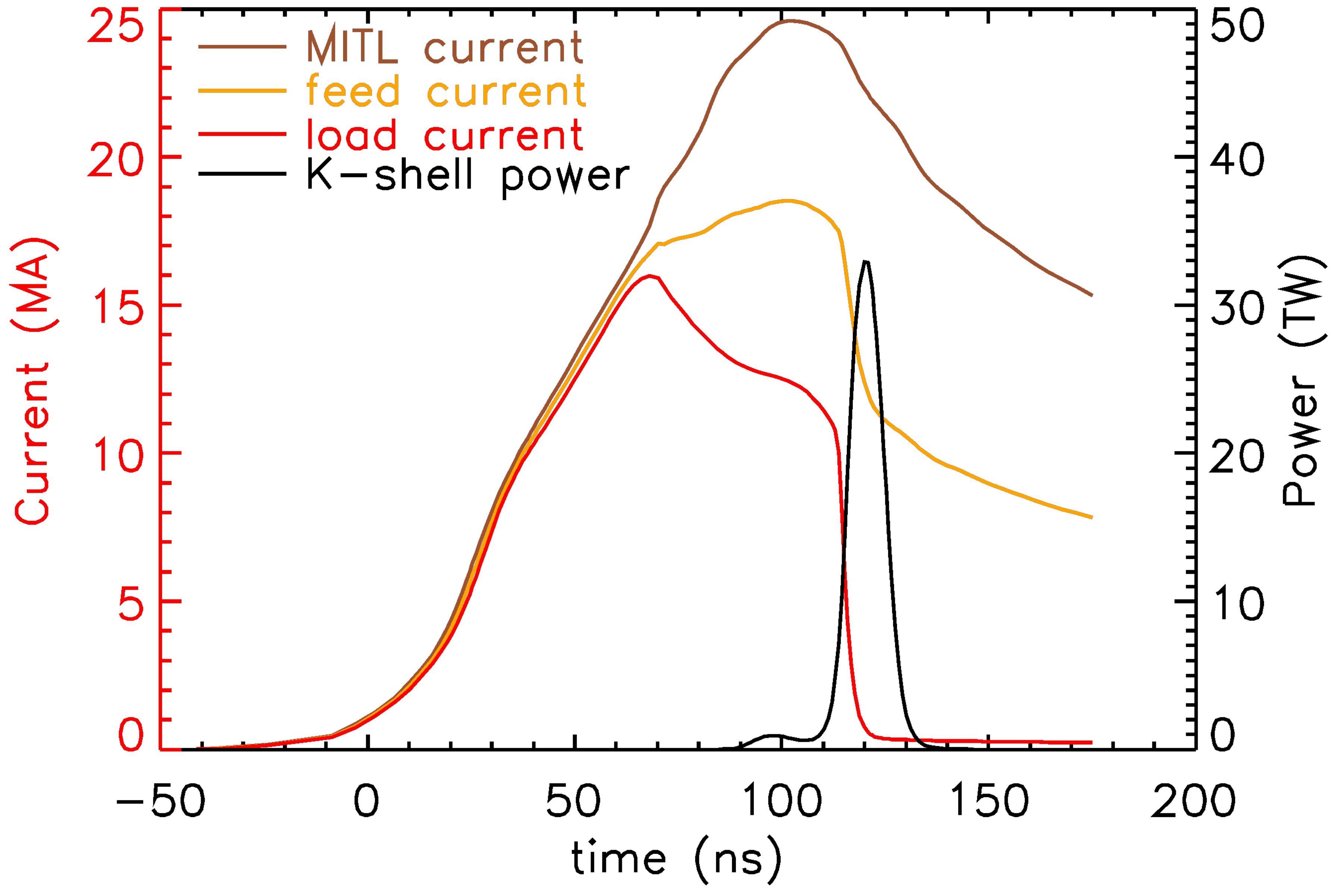
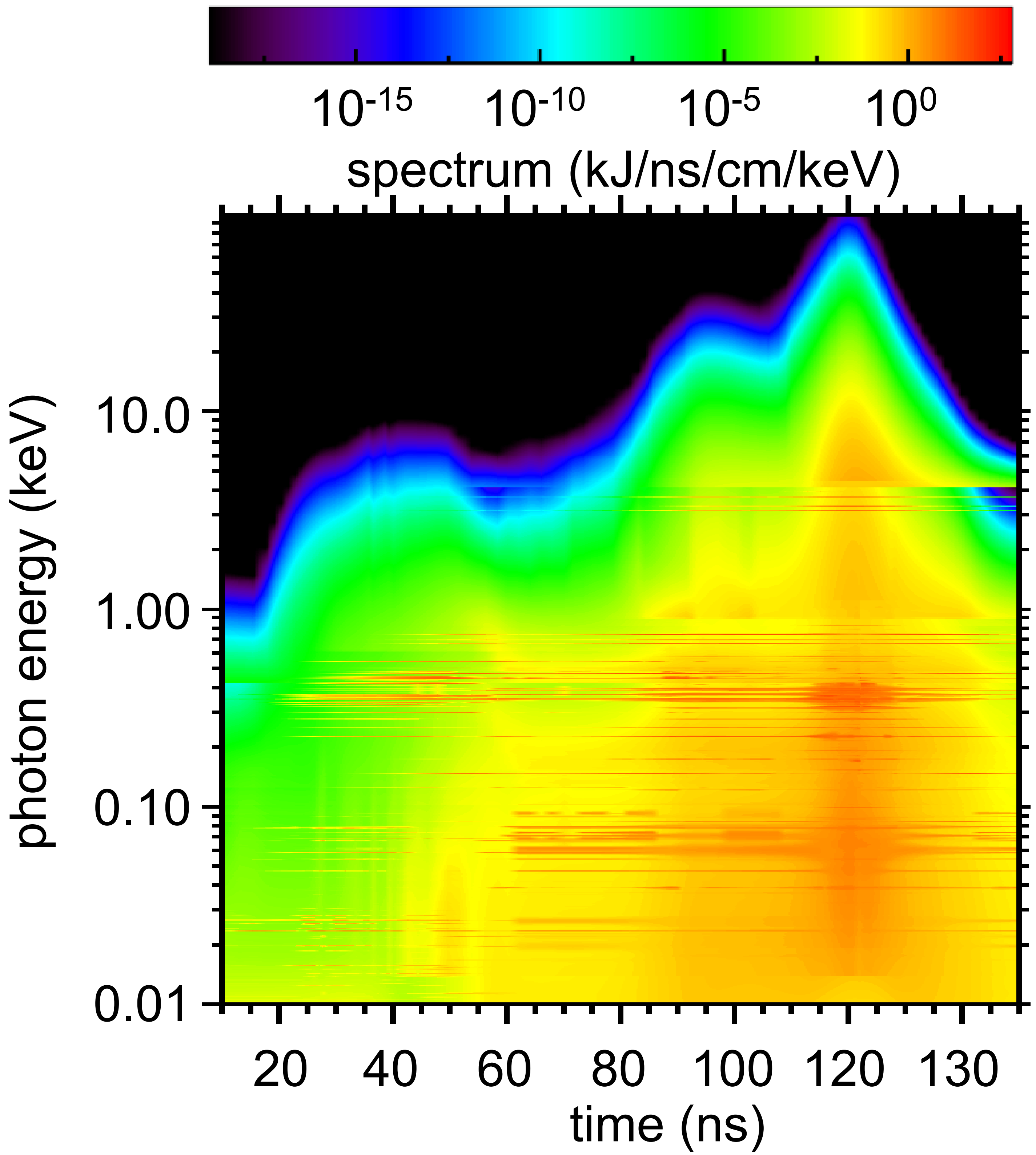
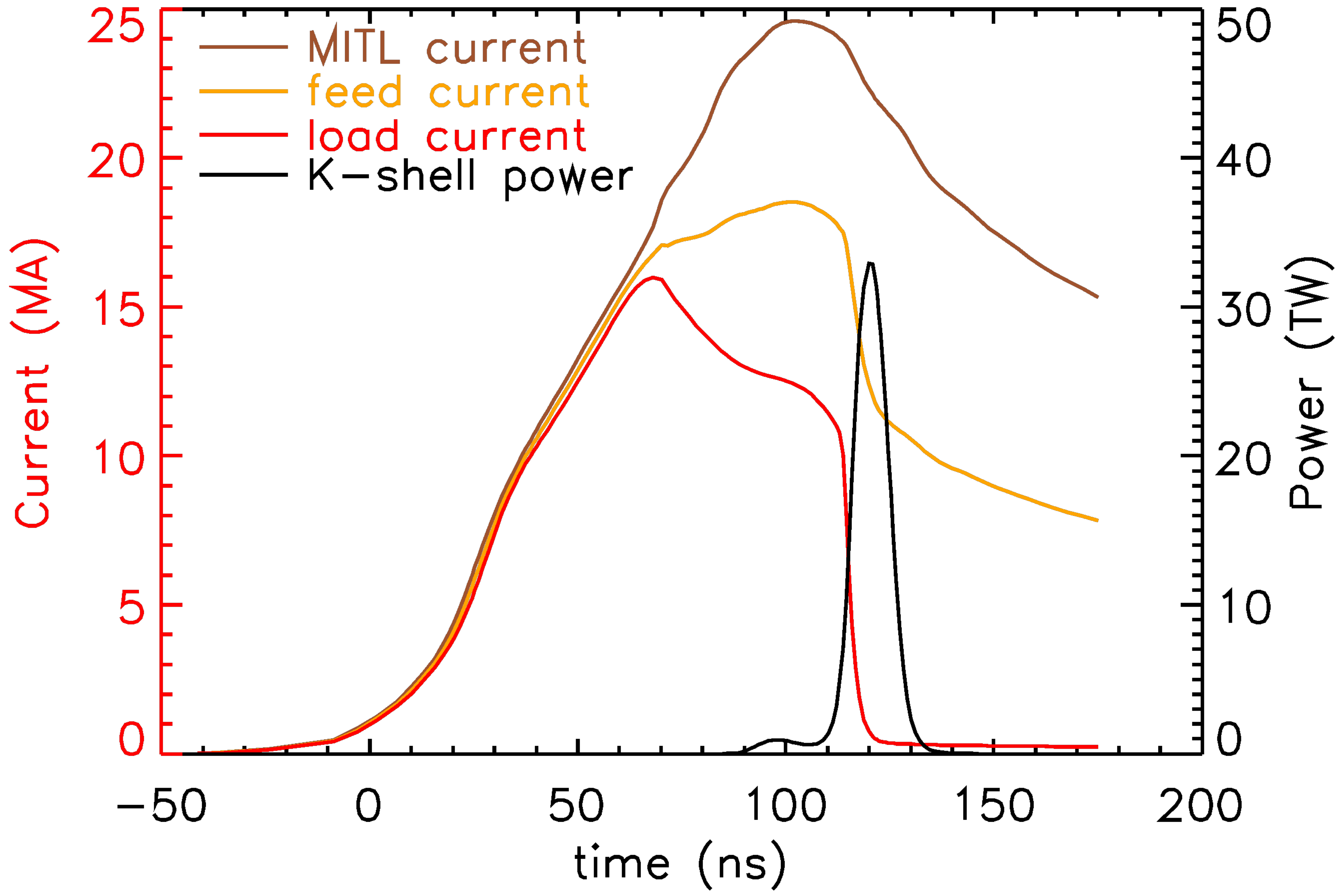
Current waveforms, x-ray powers, and spectra assuming time-dependent ground state level populations



K-shell yield: 358 kJ



The Ly-α/He-α+IC line ratio decreased when using time-dependent ground state level populations



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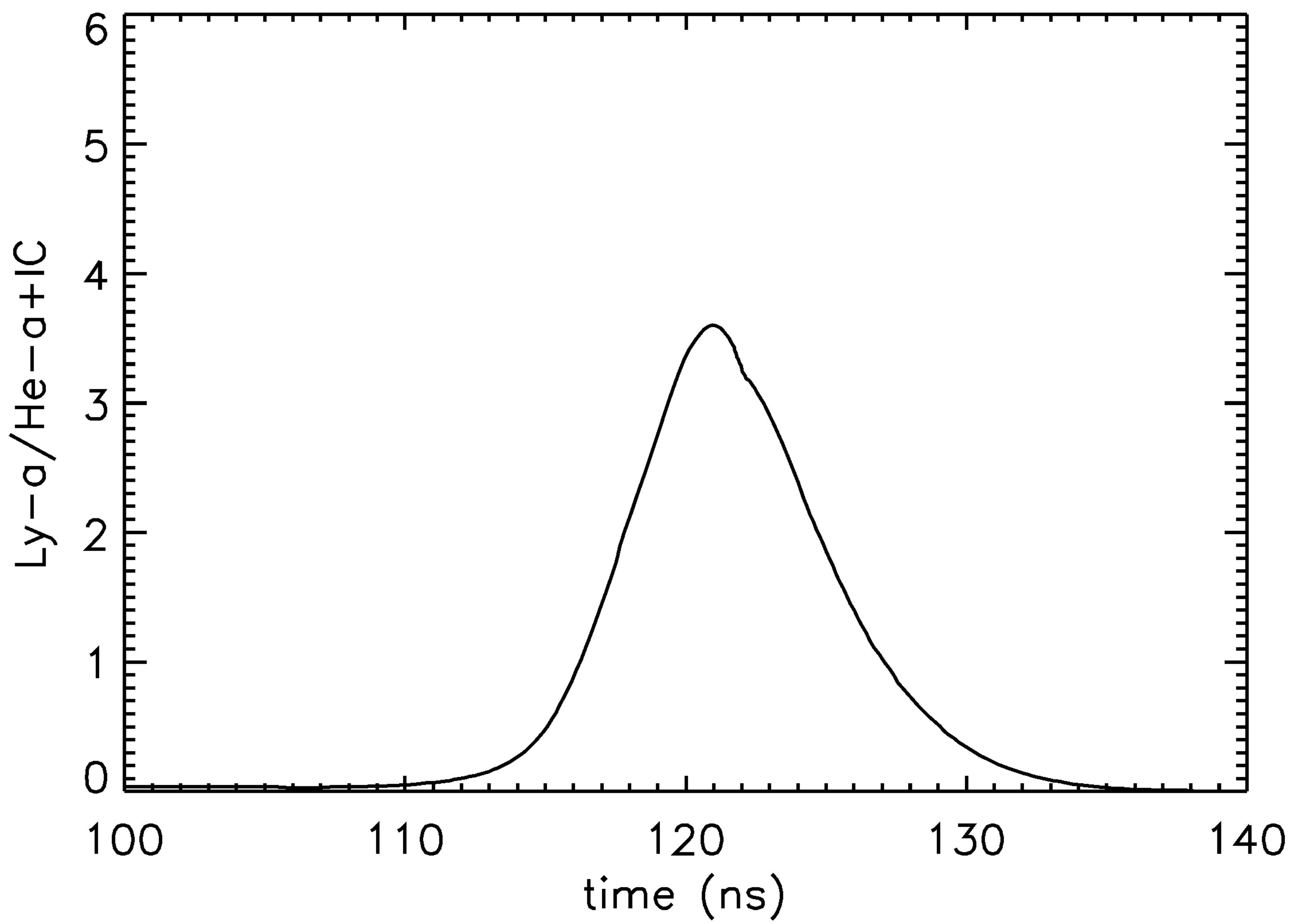

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