Modeling of spectral opacities of near-LTE aluminum plasmas

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Numerical modeling of radiative properties of multicharged-ion plasmas using DTA-approach

A numerical model Spectr-DTA based on detailed description of bound-bound and bound-free radiation/ absorption spectra (Detailed Term Accounting: DTA-approach) is developed to calculate radiative properties (spectral emissivities & opacities) of multicharged-ion plasmas

- to analyze & model radiation/absorption spectra of dense plasmas being measured in laser-plasma experiments;
- to benchmark approximate statistic methods for simulating radiative properties of dense plasmas.

Spectr-DTA model to calculate spectral opacities (1)

- **Ionization balance & ion-state populations are found from**
  - **modified ionization-equilibrium Saha equations for superconfigurations allowing for plasma-density & electron degeneracy effects solved with the superconfiguration Spectr-STA model + Boltzmann distribution over detailed terms (LTE);**
  - **calculations with other collisional-radiative models (NLTE).**
- **Spectr-DTA uses pre-calculated atomic data for bound-bound (atomic-state properties, multipole transition matrix elements) & bound-free radiative transitions (photoionization cross-sections for ground + excited levels, if necessary) contributing to the spectral range of interest.**
- **Voigt lineshapes for transitions include Doppler and homogeneous (autoionization, radiative, & electron-collisional) broadening.**
- **Detailed Stark-broadened lineshapes may also be employed, if necessary & reasonable (more expensive).**

Spectr-DTA model to calculate spectral opacities(2)

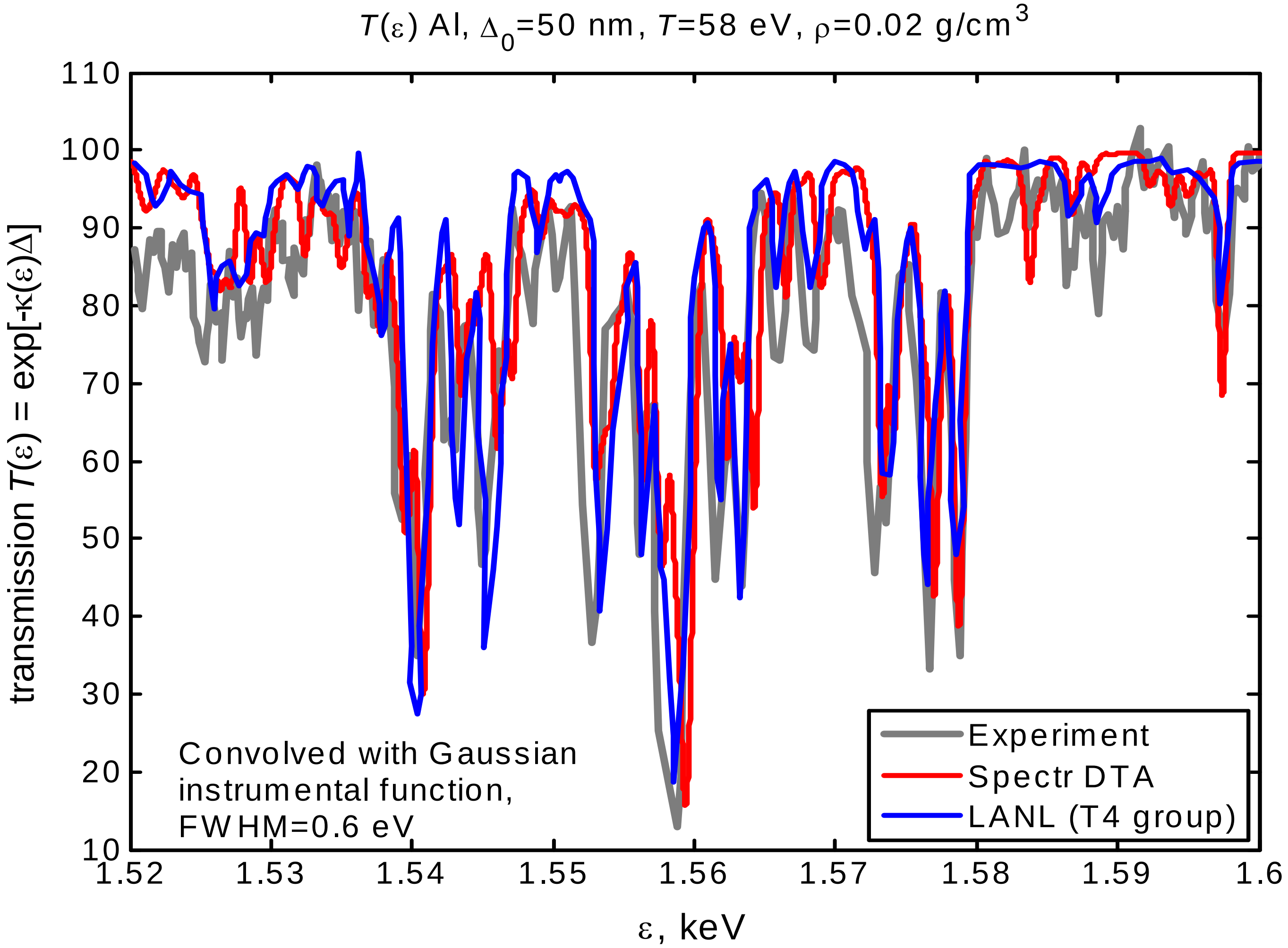
Generalized theoretical model LineDM for calculating local line radiation/ absorption spectra for arbitrary multielectron ions in plasmas [P.A. Loboda et al. LPB **18**, 275 (2000)]:

- **consistent implementation of the density-matrix approach;**
- **arbitrary bound-bound transitions;**
- **most important line-broadening mechanisms: ion quasi-static & electron Stark broadening, natural, autoionization, and Doppler broadening;**
- **enables to describe the effects of plasma microfield and radiation field on the population kinetics of ionic states (individual calculations).**

Input atomic data for Spectr-DTA

- Spectroscopic data are calculated for detailed radiative transitions between relativistic ionic terms with
  - an improved version of the GRASP^2 package (up to 2500 detailed terms and $3\text{x}10^6$ transitions in a single GRASP^2 run)
  - parametric-potential relativistic FAC code (somewhat less accurate than GRASP^2, but easier to run)
- Autoionization widths, photoionization cross-sections are calculated using the distorted-wave approach with the FAC code (if necessary).

LLNL experimental data for near-LTE Al transmission at T=58±4 eV, $\rho = 0.02\pm0.007$ g/cm^3 vs. DTA-model calculations (1)



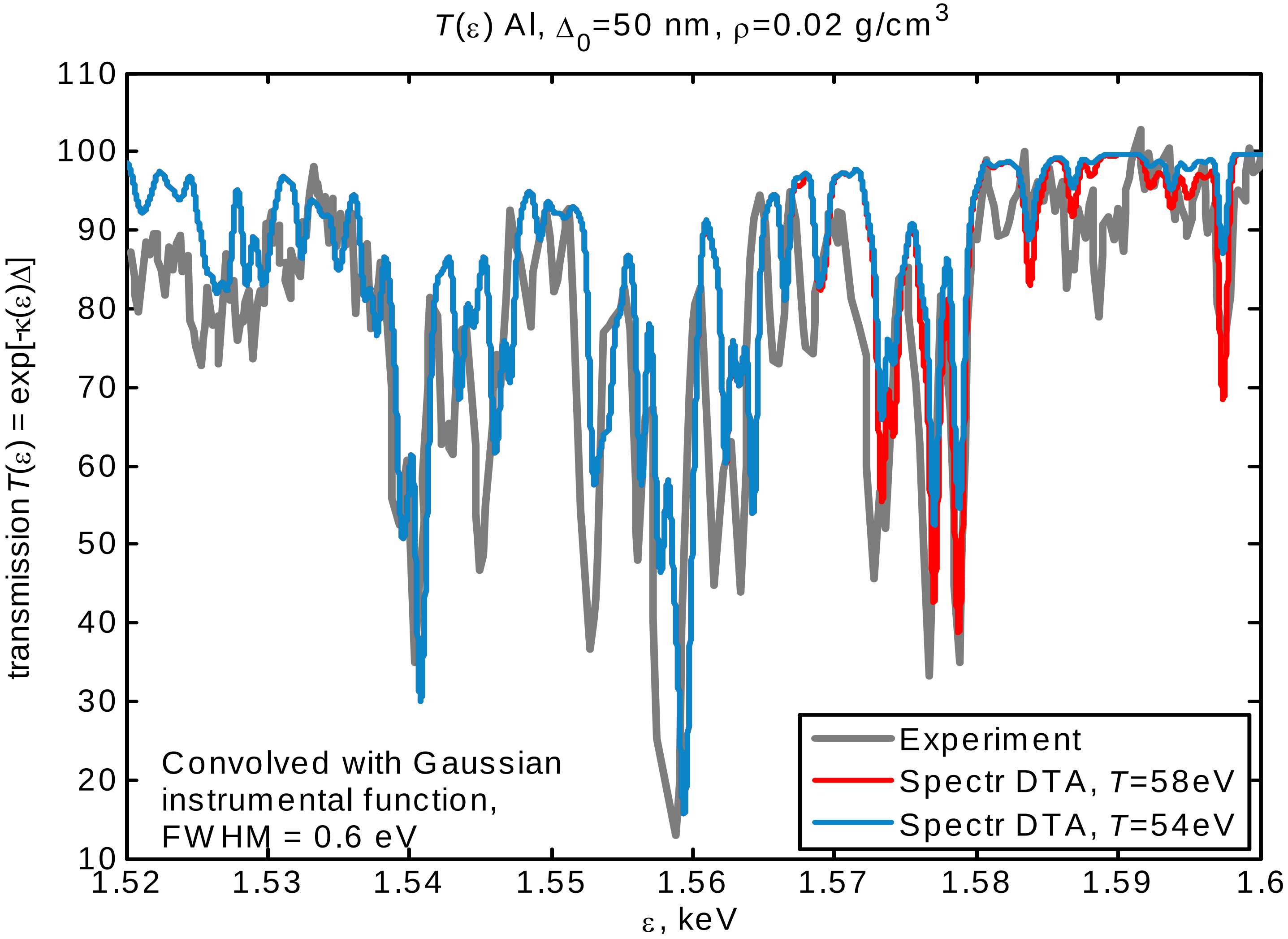
$\Delta_0 = 0.05\ \mu m$

$\Delta = \Delta_0 \cdot \rho_0/\rho = 67.5\ \mu m$

Ion	Fraction	Lines
[Li]	12%	470
[Be]	16%	10646
[B]	42%	58558
[C]	31%	141911
[N]	8%	115144

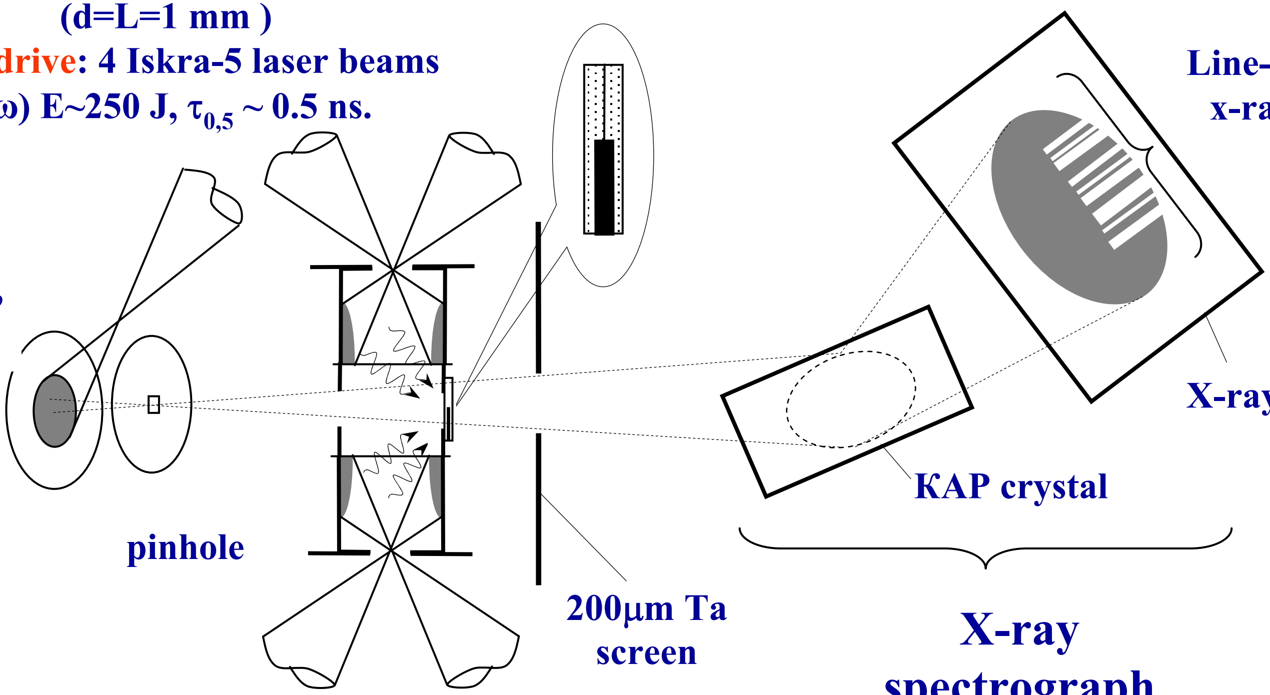
T.S. Perry, et al. Phys. Rev. Lett., **67**, 3784-3787 (1991)

LLNL experimental data for near-LTE Al transmission at T=58±4 eV, $\rho = 0.02 \pm 0.007$ g/cm^3 vs. DTA-model calculations (2)



Iskra-5 experiments for near-LTE Al transmission at RFNC VNIIEF

One-sided x-ray irradiation experiments with Al samples Δ_0=0.9 & 0.1 μm



X-ray drive: – two laser-driven “illuminator” hohlraum-type targets (d=L=1 mm)

Laser drive: 4 Iskra-5 laser beams (2ω) E~250 J, $\tau_{0,5}$ ~ 0.5 ns.

1 μm-CH sandwiched x-ray heated Al sample

Line-absorption x-ray spectra

Dy x-ray backlighter, delay time ~ (0.7-1) ns

pinhole

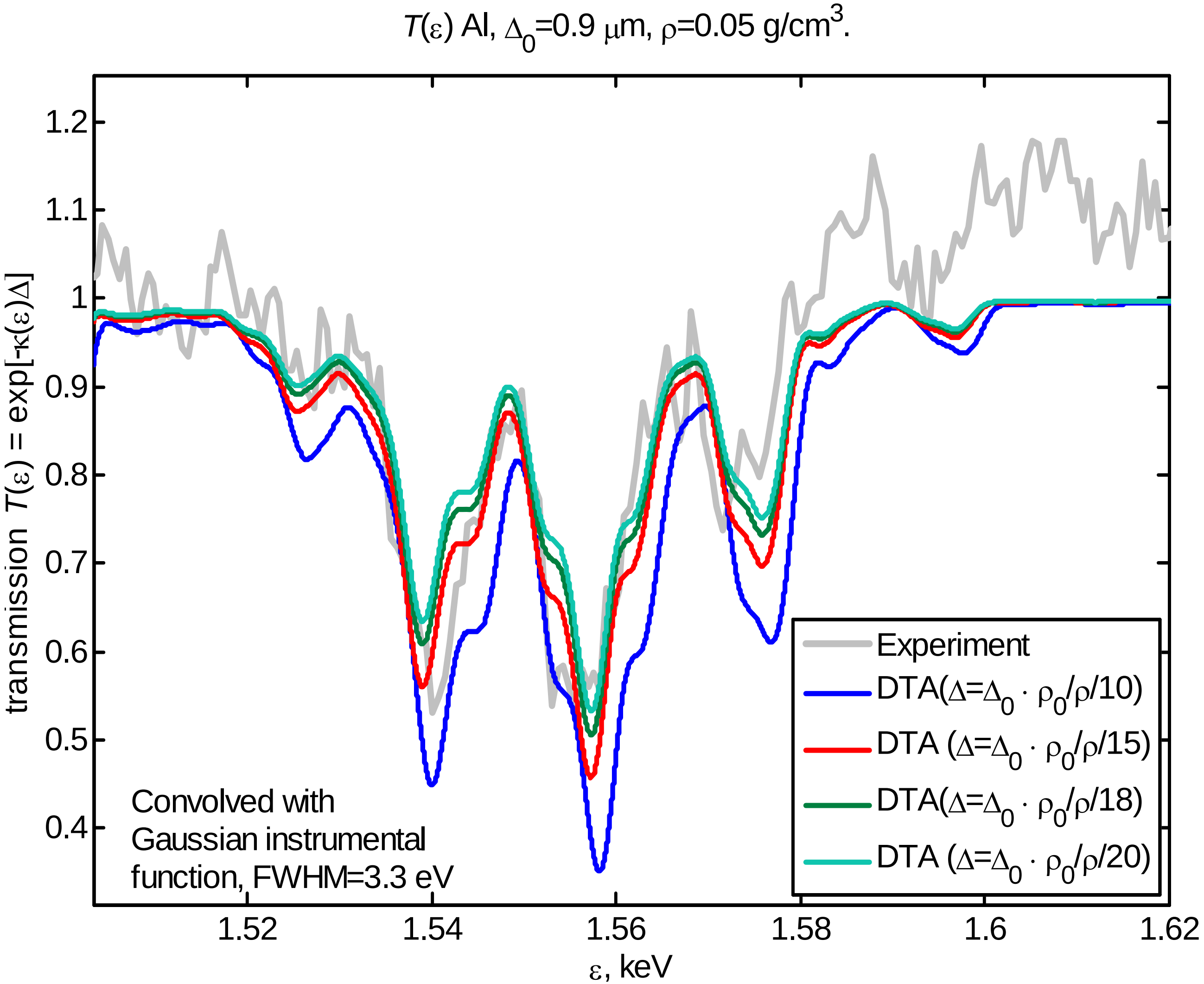
200μm Ta screen

X-ray film

KAP crystal

X-ray spectrograph

Measured near-LTE transmission of Al radiatively heated by laser-driven “illuminator” hohlraum-type targets in 4-beam Iskra-5 experiment (2005) vs. Spectr-DTA calculations at T=60 eV, ρ = 0.05 g/cm^3


$T(\varepsilon)$ Al, Δ_0=0.9 μm, ρ=0.05 g/cm^3.

Convolved with
Gaussian instrumental
function, FWHM=3.3 eV

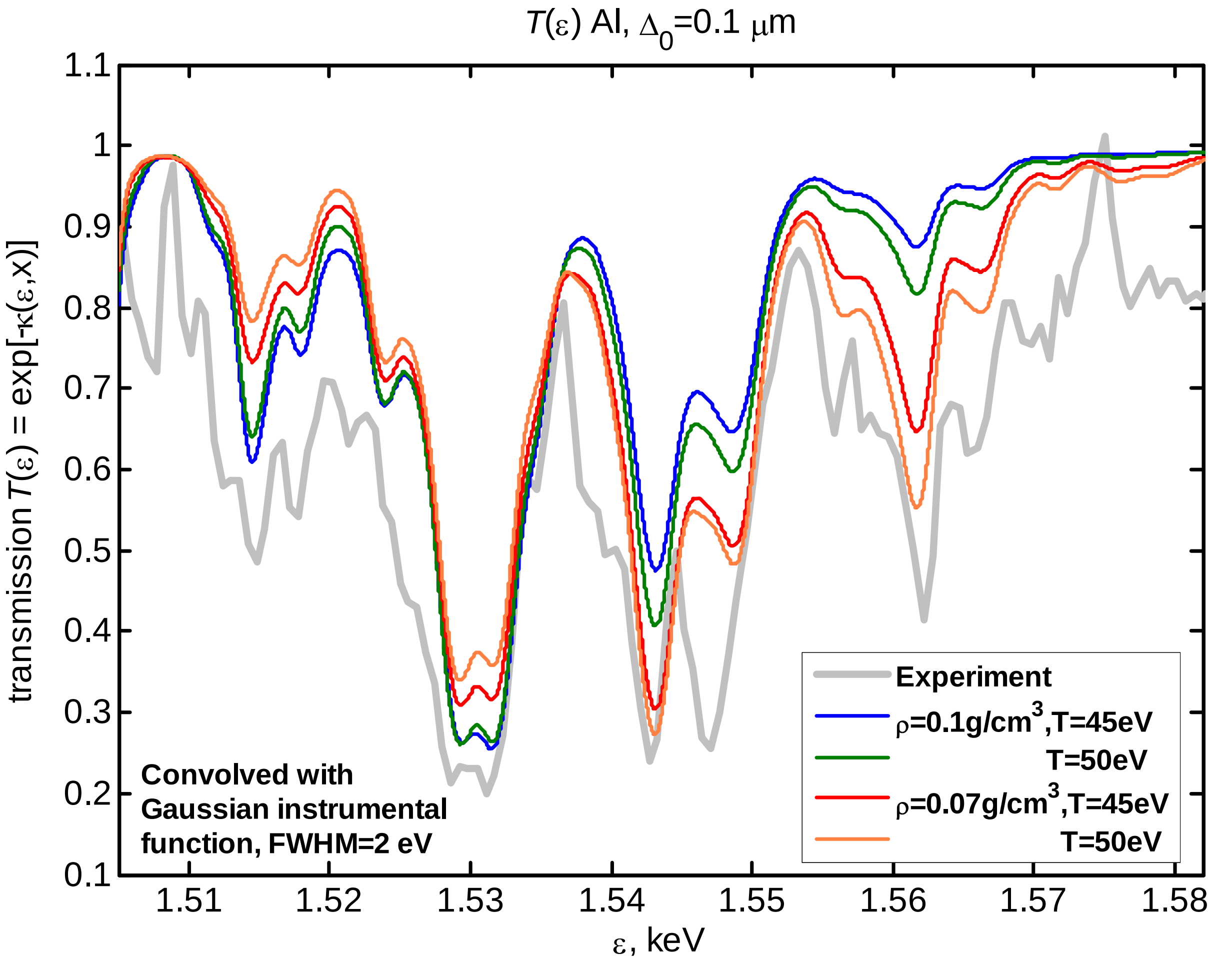
“Thick” sample

Δ_0 = 0.9 μm

$\Delta = \Delta_0 \cdot \rho_0/\rho$

Ion	Fraction	Lines
[Li]	7%	470
[Be]	32%	10646
[B]	36%	58558
[C]	16%	141911
[N]	2%	115144

Measured near-LTE transmission of Al radiatively heated by laser-driven "illuminator" hohlraum-type targets in 4-beam Iskra-5 experiment (April, 2007) vs. Spectr-DTA calculations



"Thin" sample

$\Delta_0 = 0.1\ \mu m$

$\Delta = \Delta_0 \cdot \rho_0 / \rho$

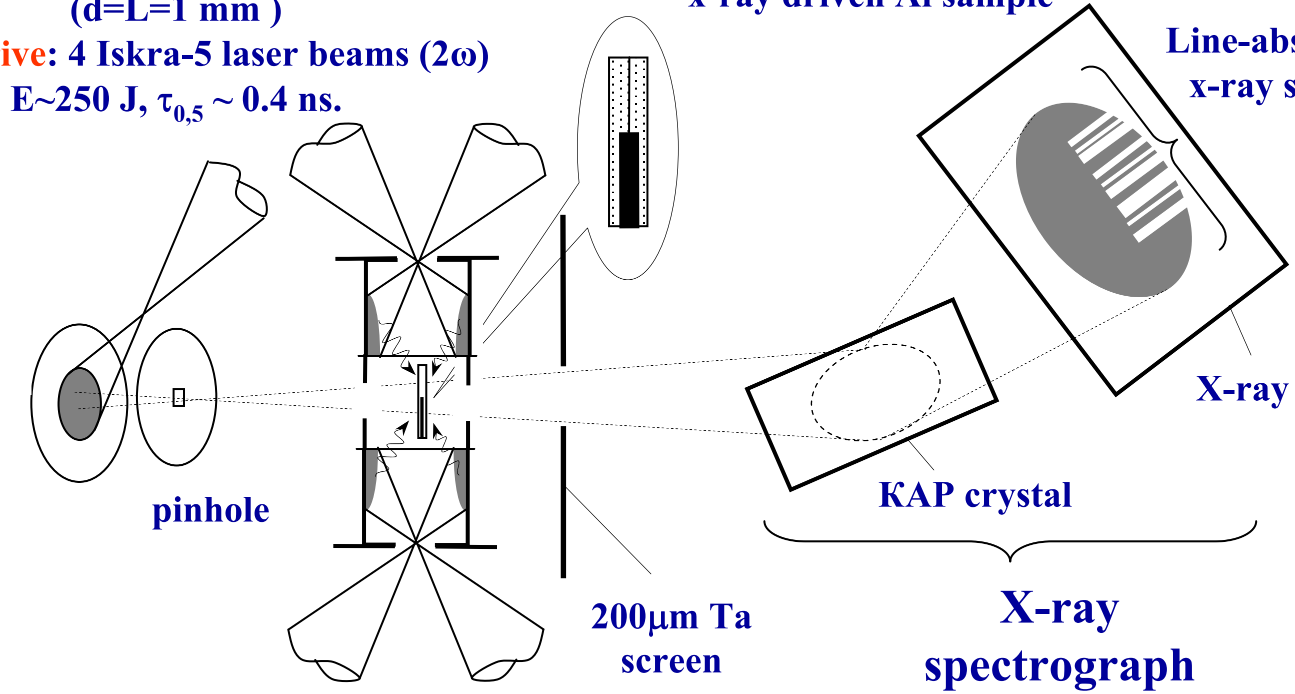
Ion	Fraction	Lines
[Be]	4%	10646
[B]	24%	58558
[C]	43%	141911
[N]	24%	115144
[O]	5%	17136

Iskra-5 experiments for near-LTE Al transmission at RFNC VNIIEF

Inside-case x-ray irradiation experiment with Al sample Δ_0=0.1 μm

X-ray drive: – two laser-driven “illuminator” hohlraum-type targets (d=L=1 mm)

Laser drive: 4 Iskra-5 laser beams (2ω) E~250 J, $\tau_{0,5}$ ~ 0.4 ns.



1 μm-CH sandwiched x-ray driven Al sample

Line-absorption x-ray spectra

Dy x-ray backlighter, delay time ~ (0.7-1) ns

pinhole

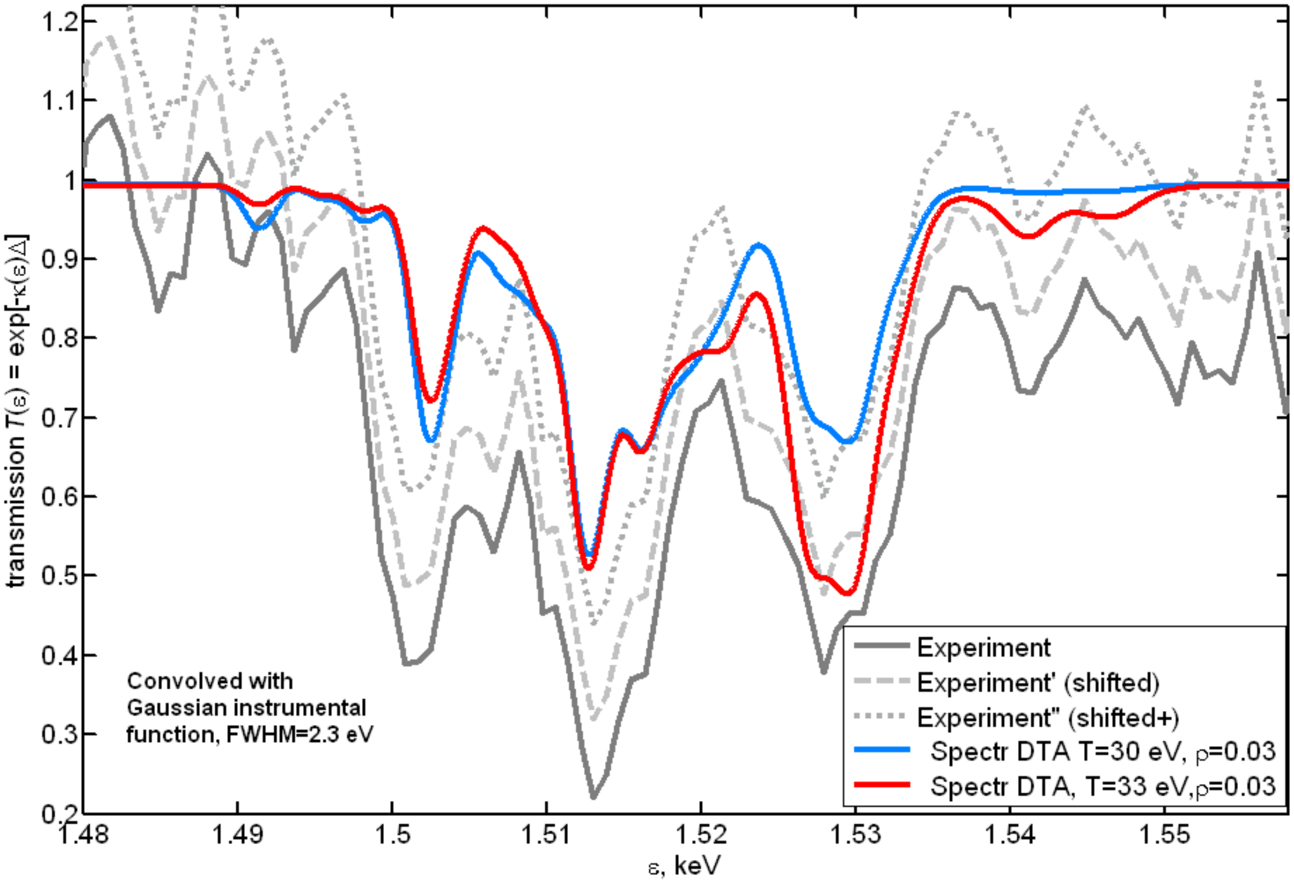
X-ray film

КАР crystal

200μm Ta screen

X-ray spectrograph

Measured near-LTE transmission of Al radiatively heated by laser-driven “illuminator” hohlraum-type targets in 4-beam Iskra-5 experiment (April, 2007) vs. Spectr-DTA calculations at $T \cong 30$ eV, $\rho = 0.03$ g/cm^3



“Thin” sample

$\Delta_0 = 0.1$ µm

$\Delta = \Delta_0 \cdot \rho_0 / \rho$

inside the case

Ion	Fraction	Lines
[B]	1%	58558
[C]	14%	141911
[N]	46%	115144
[O]	32%	17136
[F]	5%	3811

Summary

- The developed Spectr-DTA model based on detailed description of bound-bound and bound-free radiation/ absorption spectra (DTA-approach) enabled to calculate spectral opacities of near-LTE Al plasmas at the region of Al K-shell line absorption ($\varepsilon = 1.5 – 1.64$ keV) for analyzing the data of x-ray transmission laser experiments performed on the Iskra-5 laser facility.
- Plasma conditions of x-ray heated Al samples were evaluated to be in the range of $T = 30 – 60$ eV, $\rho = 0.03 – 0.1$ g/cm^3