Calculation of Xe and Sn emission spectra in discharge devices: the influence of reabsorption in spectral lines

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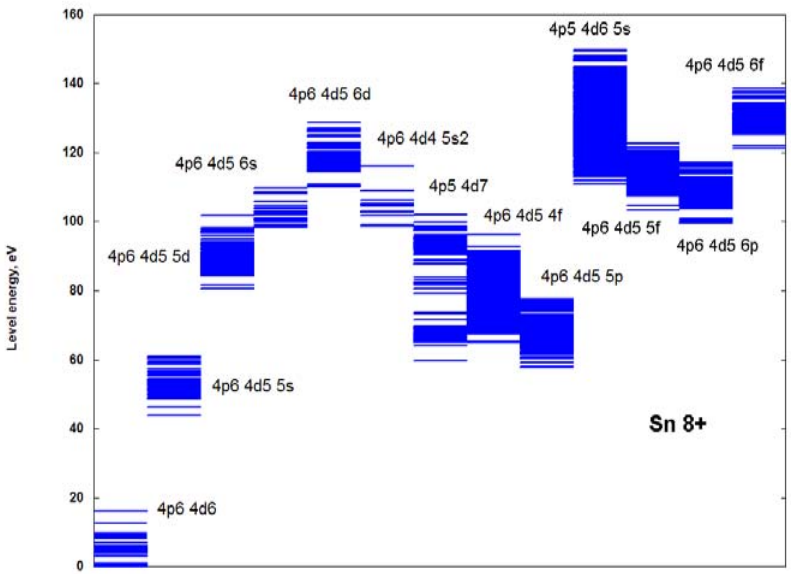
Introduction

The emission of Sn or Xe plasma near the tenth ionization degree yields an array of a huge number of overlapped spectral lines. Modeling of such plasma is very complicated both for hydrodynamics and for calculation of the emission spectra. We propose a cheap and effective approach for detailed analysis and RMHD simulations. The method is based on preliminary detailed calculations for simple homogeneous (over electron temperature and electron density) plasma layers with given radiation field. In this case is possible to fulfill the calculations including level kinetics and radiation transport with several thousands points for photon frequency grid to represent in detail each spectral line. Afterwards these data are used to obtain radiative properties and emission spectra in RMHD calculations for complex 2D geometry with nonhomogeneous nonstationary plasma at arbitrary temperature, density and optical thickness.

CRE model for multicharged optically thick Sn, Xe plasma

as an example,
energy structure for SnIX



~ 3000 energy levels per ion;

~ 300 000 spectral lines;

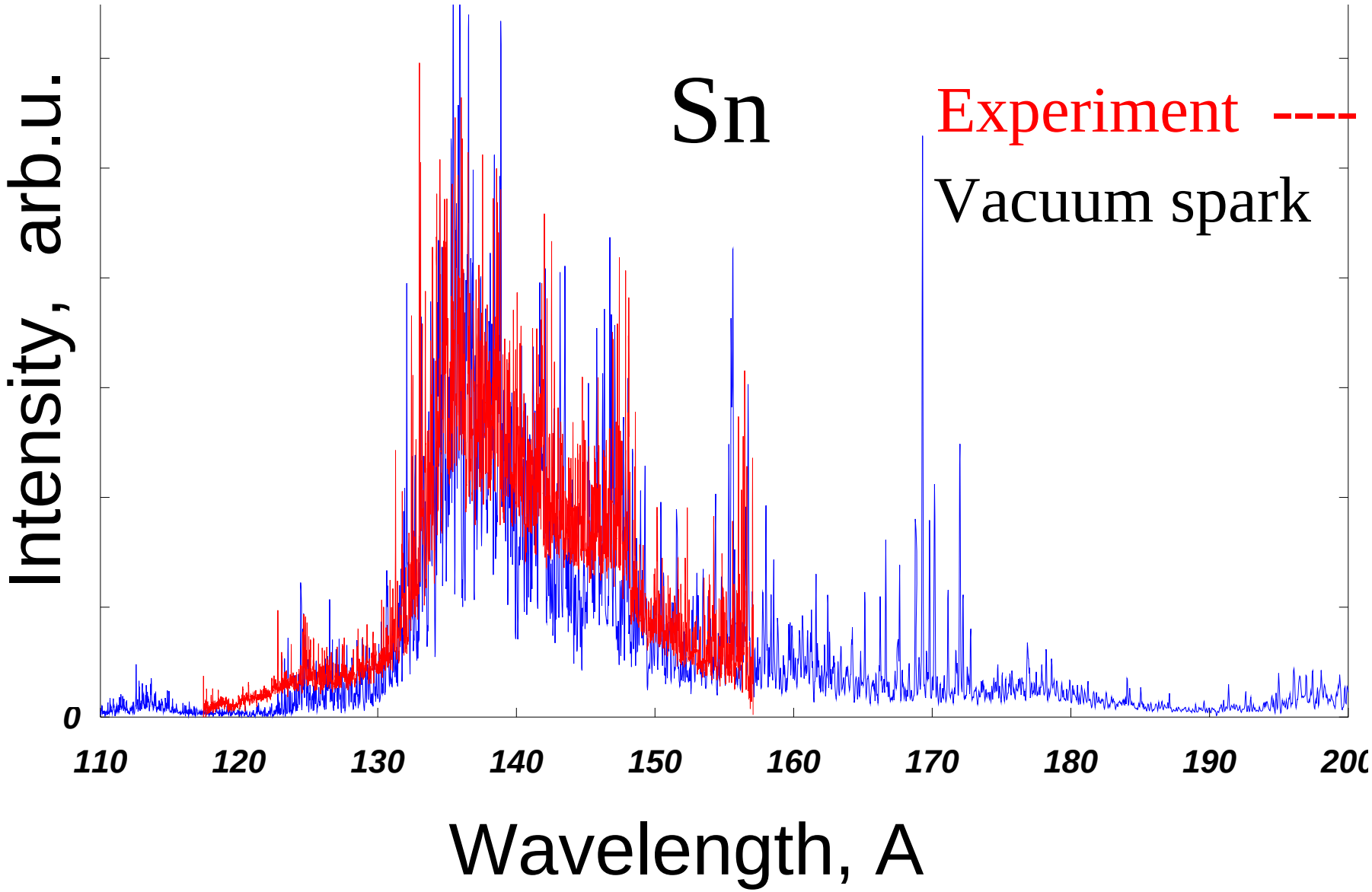
a lot of optically thick lines in different ranges of spectra;

a lot of overlapped spectral lines: averaging is required!

Level kinetics is strongly coupled with radiation

Benchmarking with high resolution measurement

Calculation, T=24 eV, Ne=5·10^{18}, L=100 μm ----



Accurate description of opacity effects in some simple cases

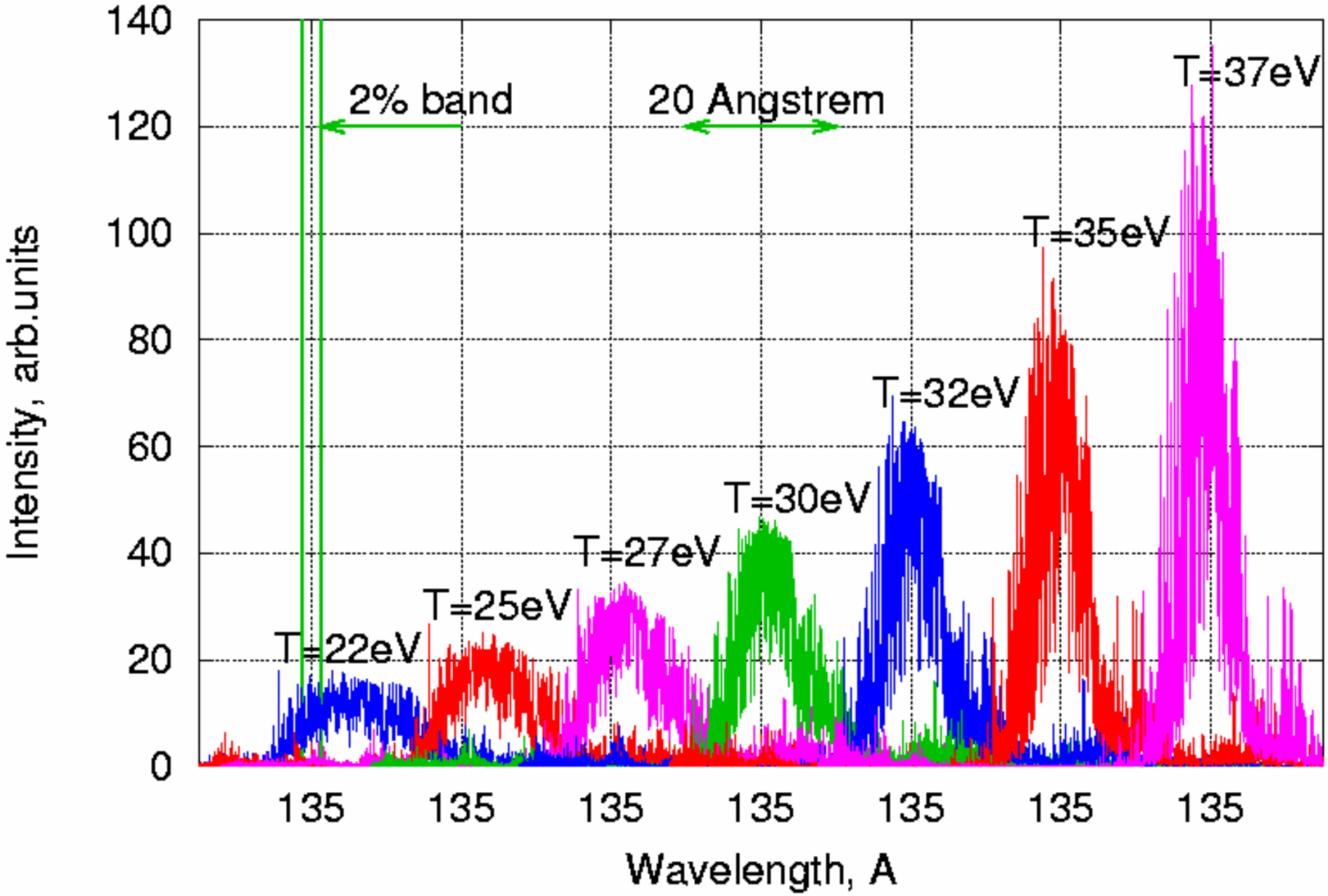
in particular, for DPP

- Isothermal 1D cylindrical column
- Collisional-radiative equilibrium –

  steady state case
- Nonhomogeneous over level populations
- Detailed radiation transport

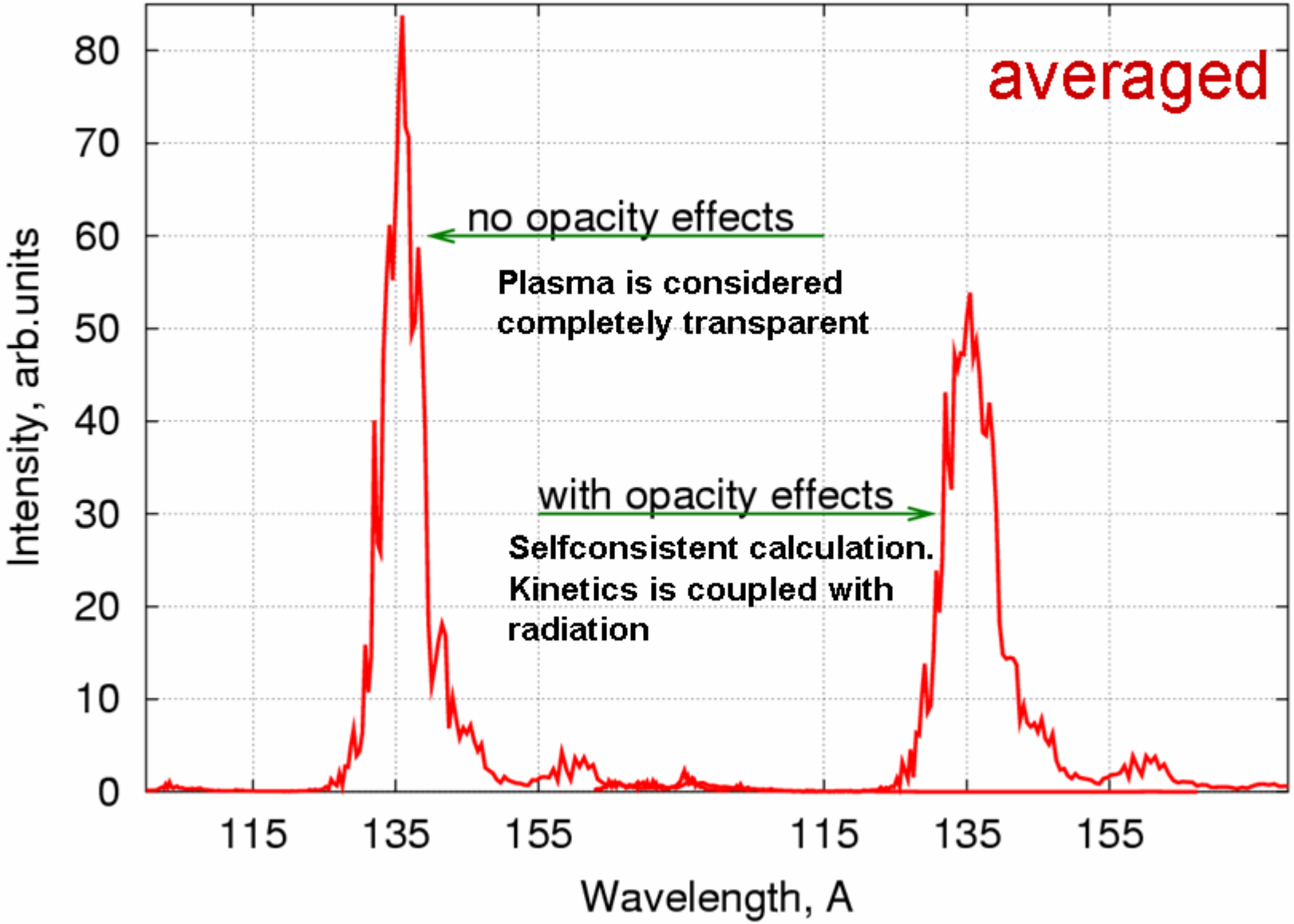
  with 20000 photon groups

Results of calculations for simple cases



Emission spectra of Sn at R=0.01 cm at $N_e=10^{19}$ 1/cm^3

Influence of opacity effects

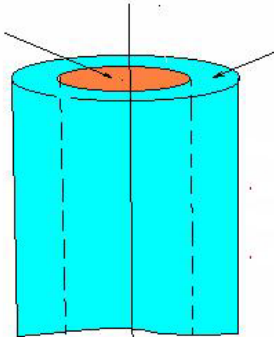


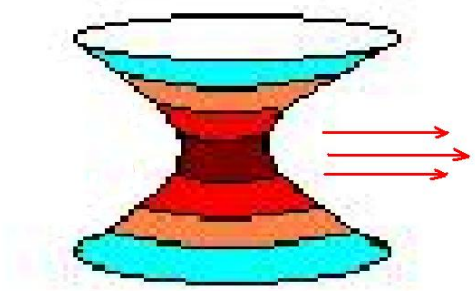
Sn, T=32.5 eV, Ne=10^{19} 1/cm^3, R=0.01 cm

Description of pinch on the basis of isothermal cylindrical columns

- Collisional-radiative equilibrium
- Equilibrium pinch dynamics
- Set of isothermal cylindrical columns

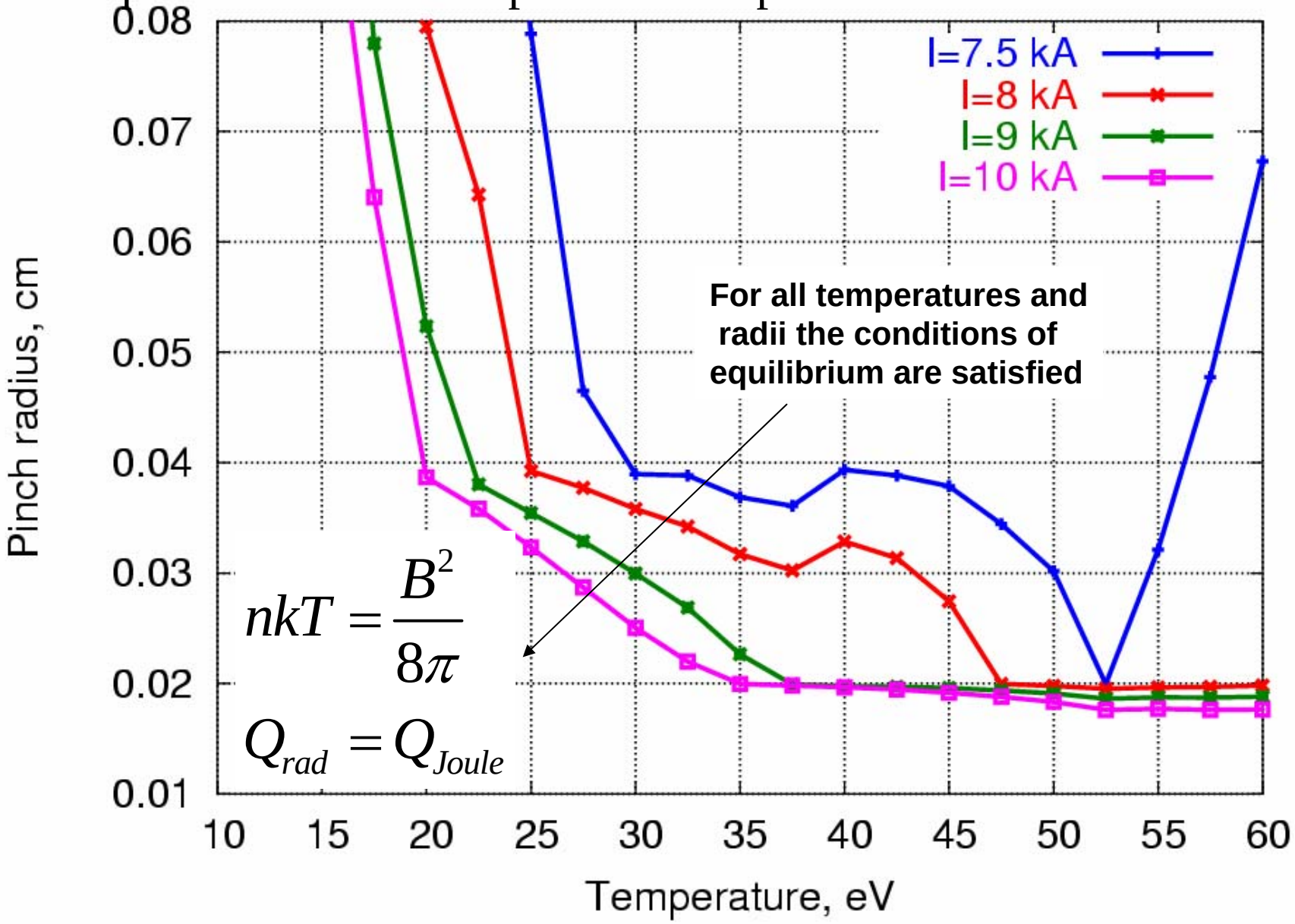
  with L ~ 3R, given T, N_e, nonhomogeneous over ionization stage and level populations
- Detailed kinetics with minimal averaging
- Detailed radiation transport

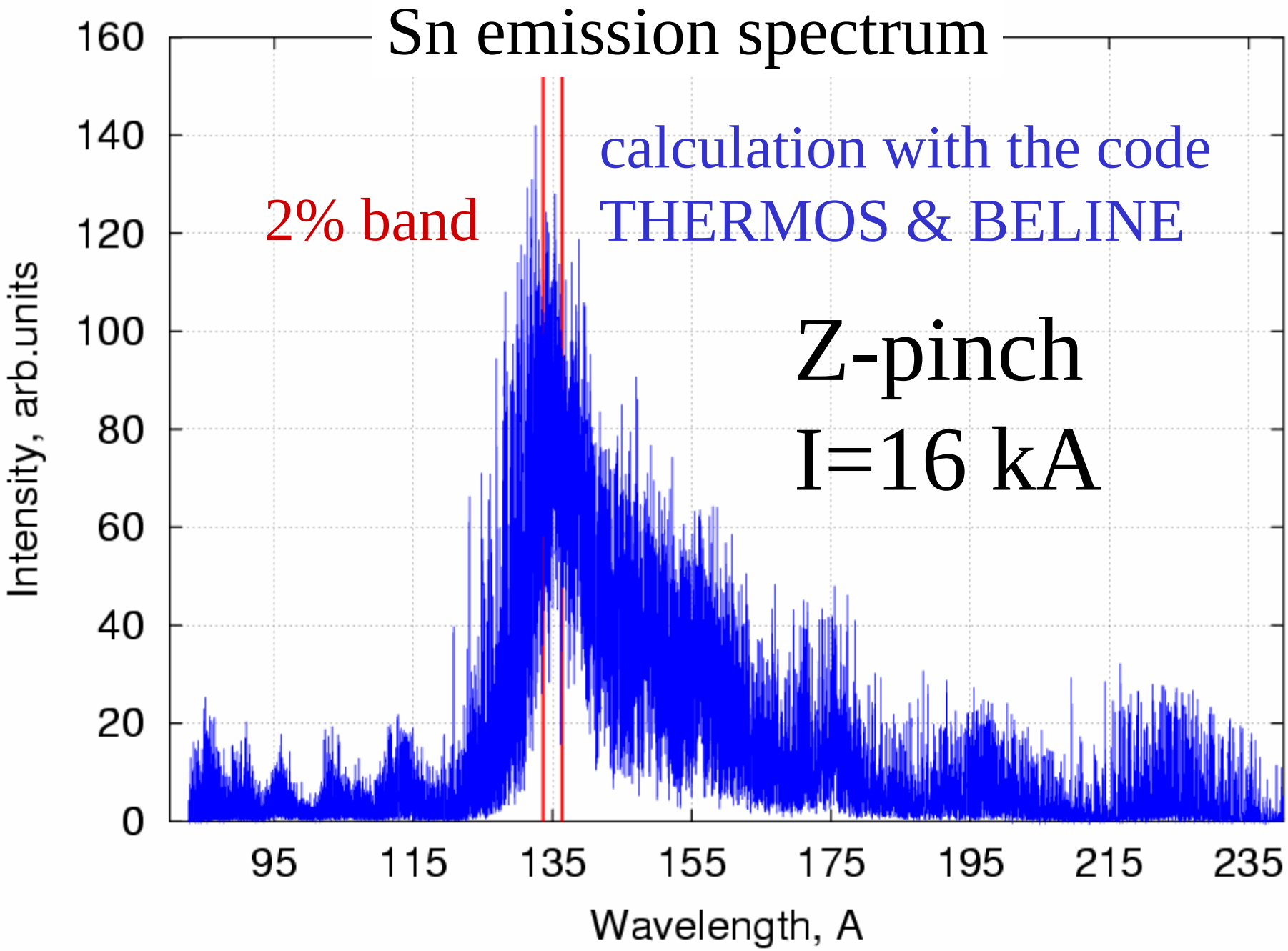




Pinch dynamics

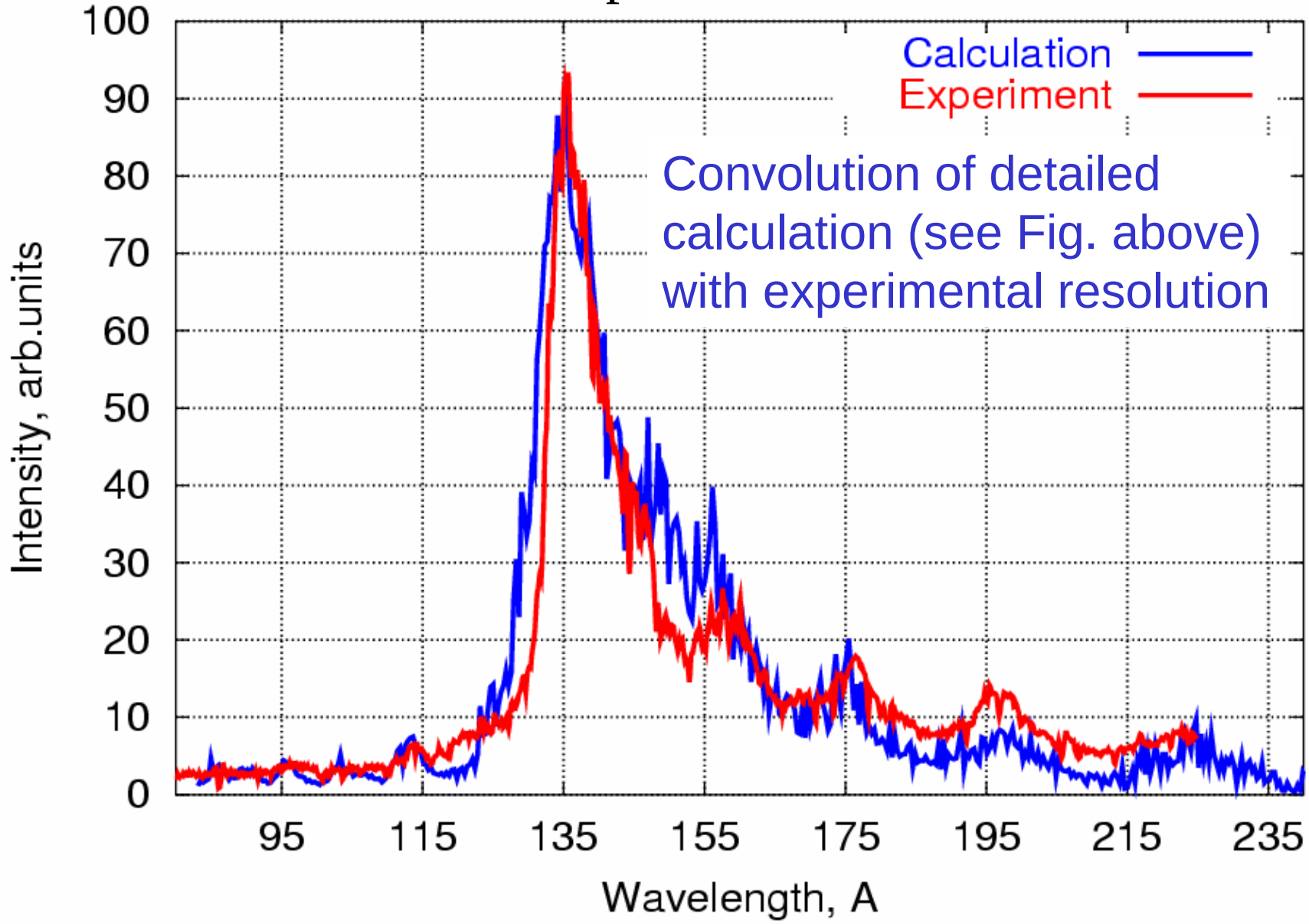
Equilibrium radius of pinch vs temperature at different currents



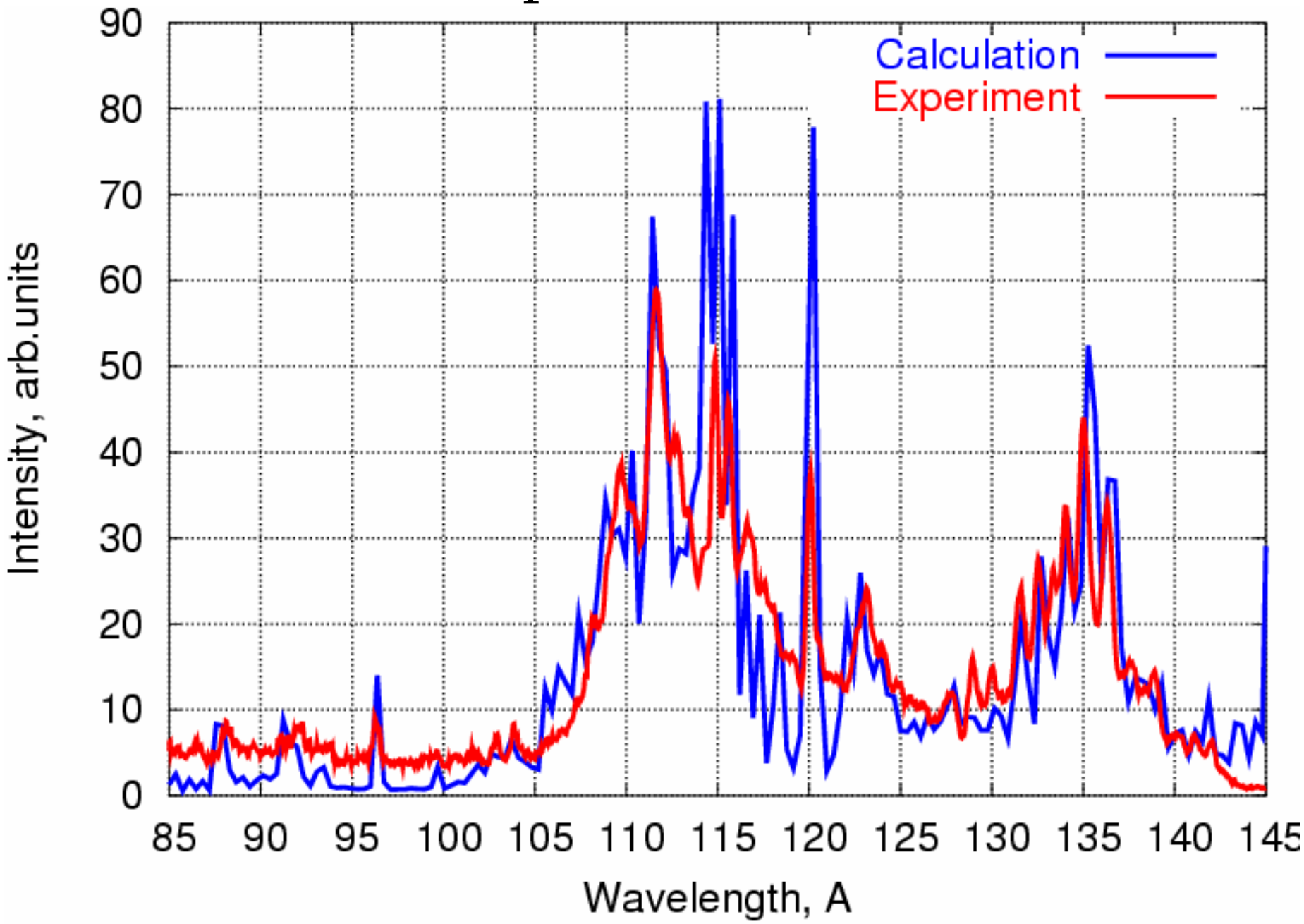

Sn emission spectrum
calculation with the code
THERMOS & BELINE
2% band
Z-pinch
I=16 kA
Intensity, arb.units
Wavelength, A
0
20
40
60
80
100
120
140
160
95
115
135
155
175
195
215
235

Comparison with experiment

Sn emission spectrum at current I=16 kA



Xe emission spectrum at current I=12 kA

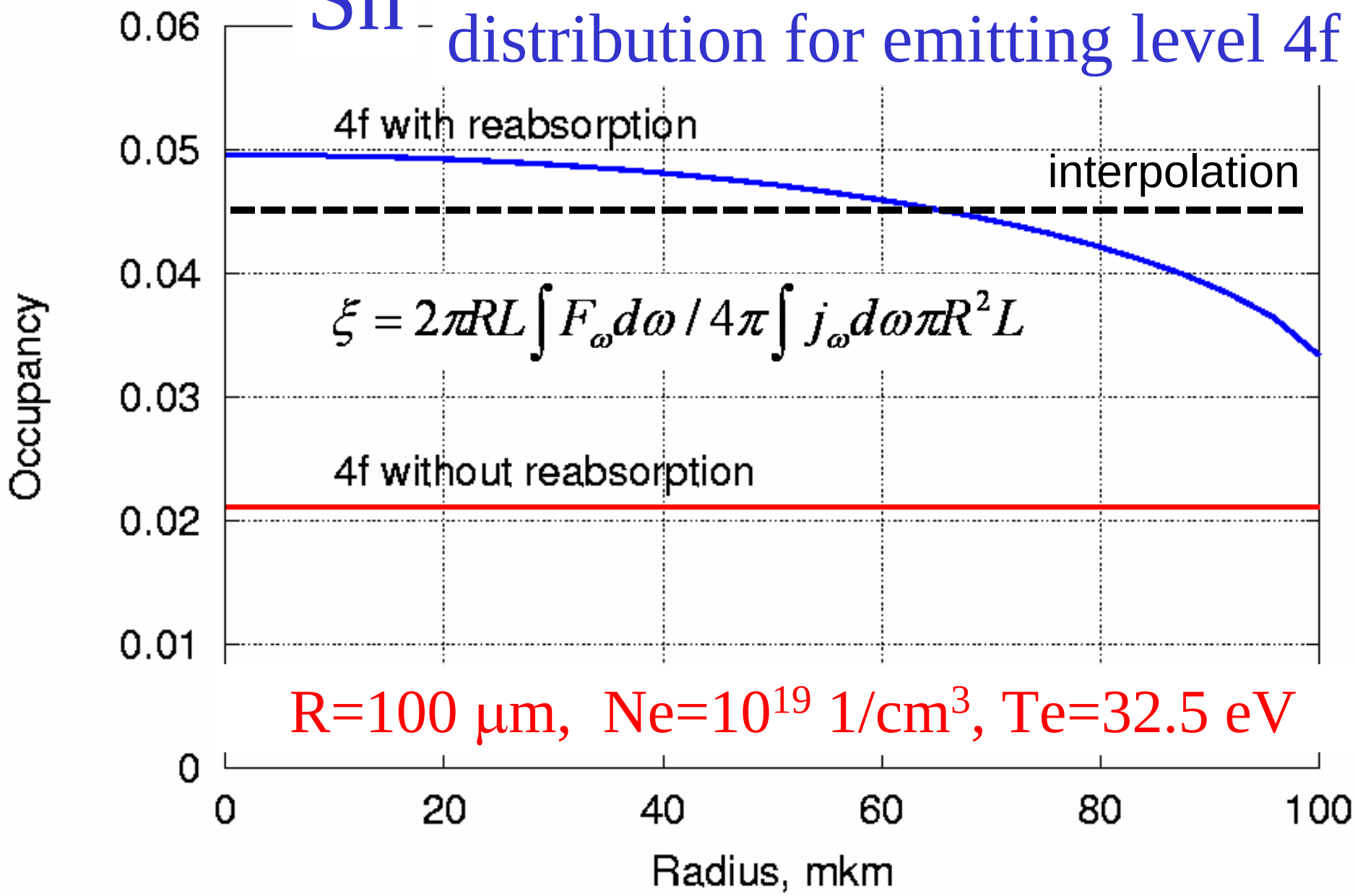


Simple solution for MHD code

At given distribution of temperature T and density N_e the calculation of ionization equilibrium and radiation transport is based on opacity and emissivity tables of two types: optically thin and optically thick (in some range of photon energies).

Opacity effects are included by using effective total escape parameter ξ, which is equal 1 for transparent case and equals 0 for optically thick case.

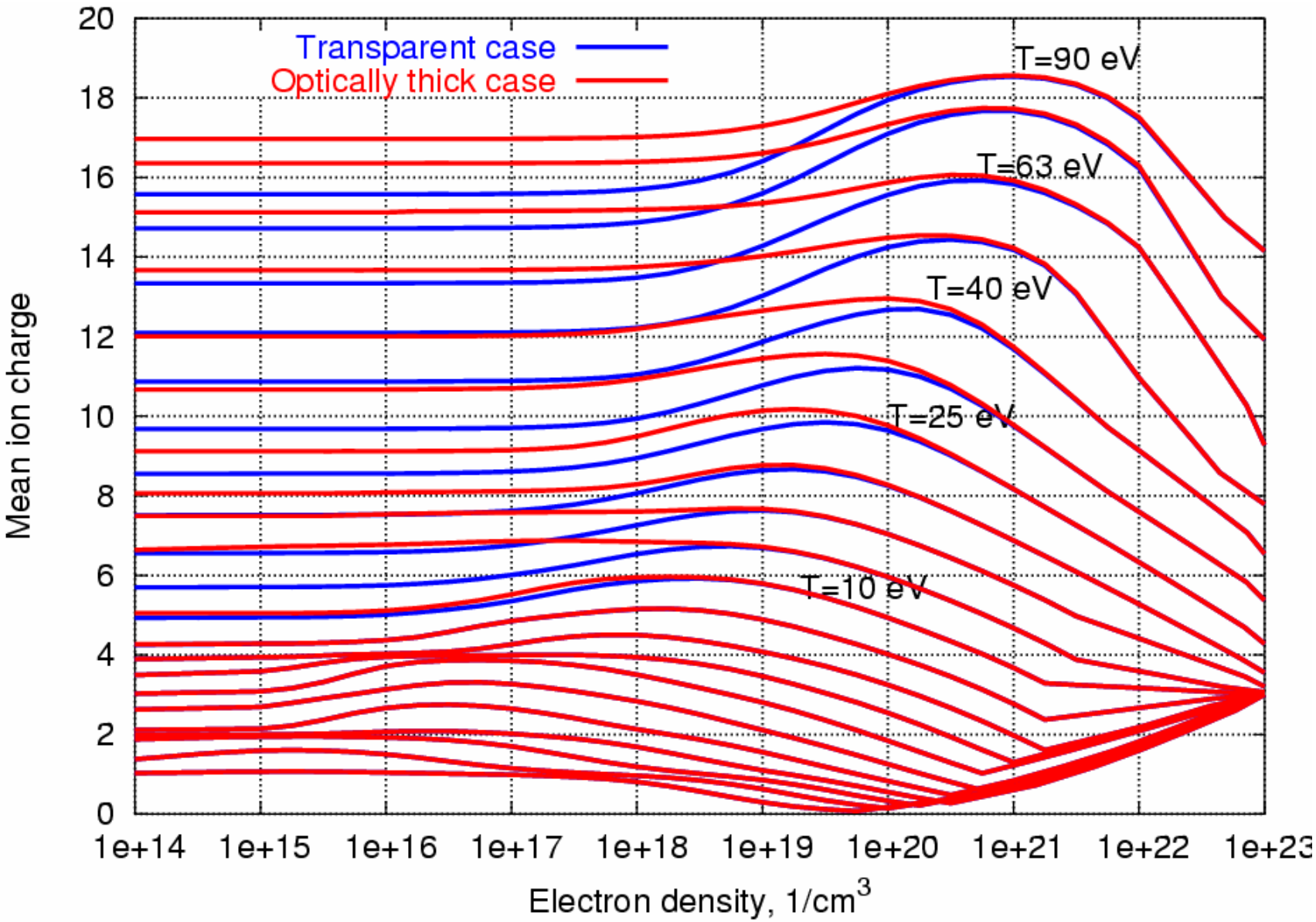
Sn - opacity affects on occupancy distribution for emitting level 4f



R=100 μm, Ne=10^{19} 1/cm^3, Te=32.5 eV

Results for ionization stage of Sn plasma:

transparent (blue) and optically thick in the range 130-135 A (red)



SUMMARY

THERMOS_BELINE code:

for modeling EUV emission spectra

The code makes possible self-consistent calculation of level kinetics and radiation transport for different plasma configurations. The code includes: radiation transport of overlapped spectral lines with arbitrary optical thickness and realistic line profiles; verified atomic database for low-Z materials (H, He, O) and also for Xe, Sn and their mixtures. It is possible to get EUV spectra in the range 80-250 A at any direction for nonhomogeneous 1D plane slab, cylindrical column or spherical target, and also for 2D axisymmetrical plasma configurations. The calculation is carried out for given distribution of ion and electron temperature and density.