Modeling of optical properties of laser and discharge plasmas in EUV range

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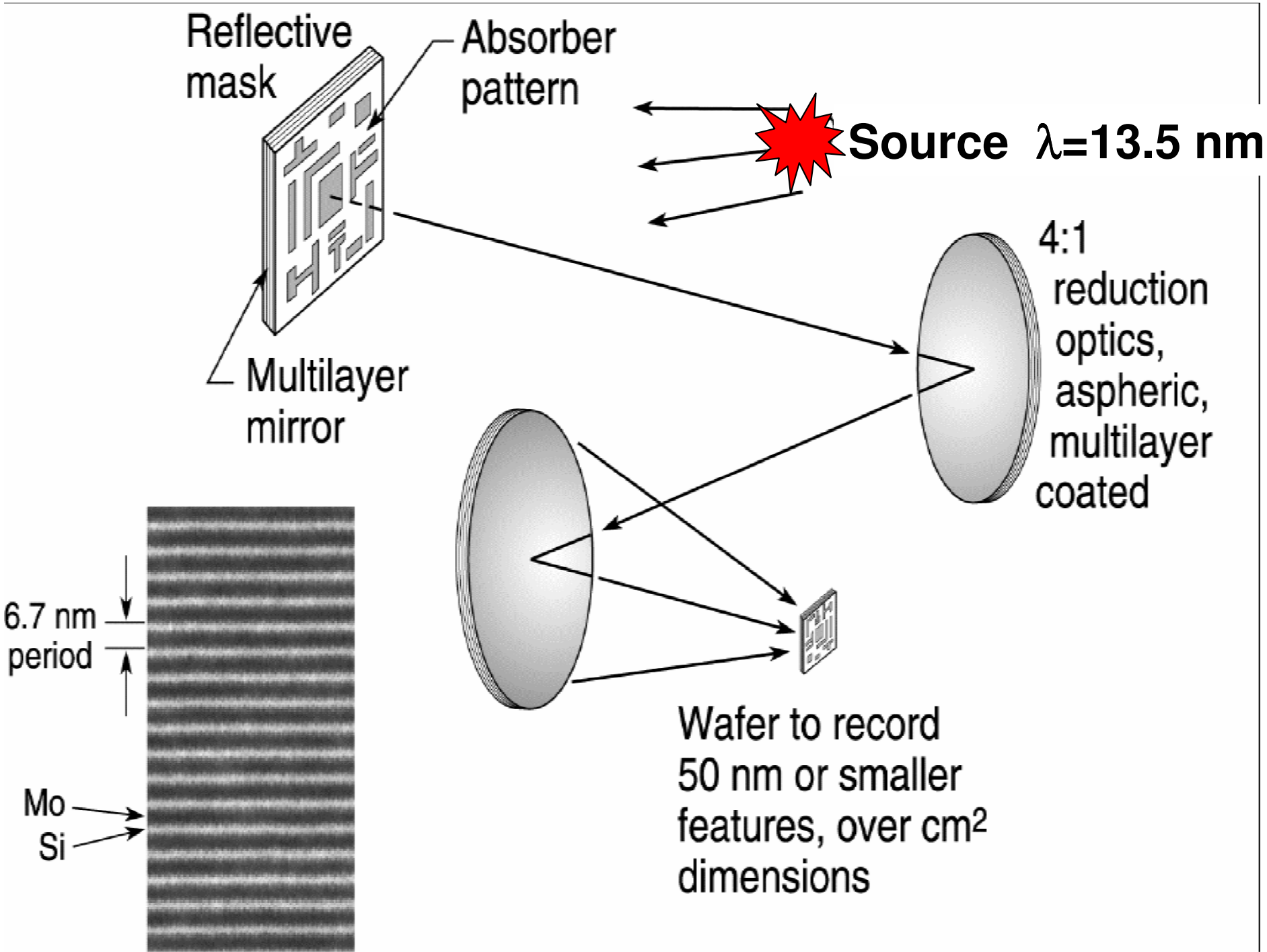
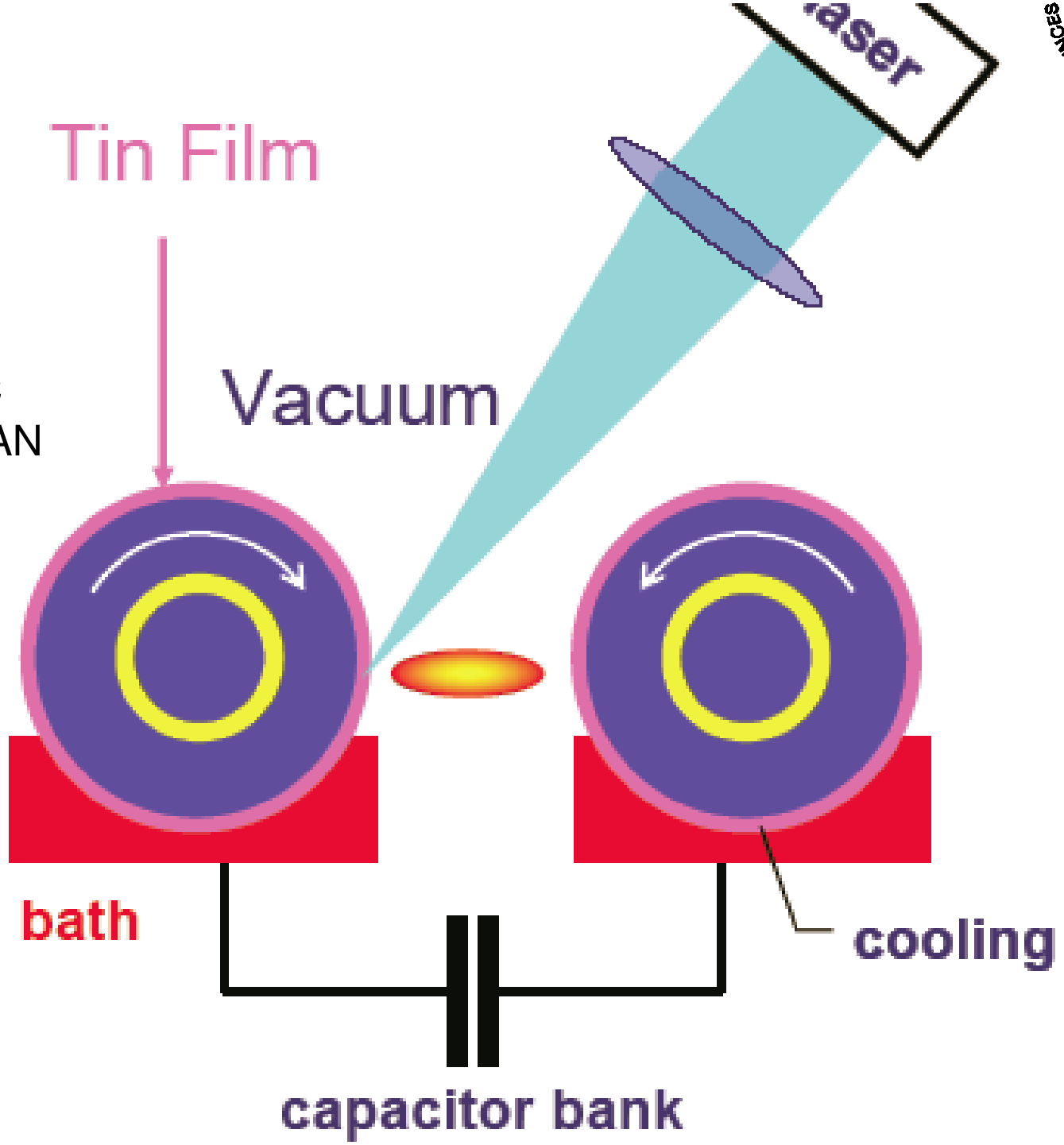
Annual Moscow Workshop on the Non-ideal Plasma Physics (NPP-2009)

EUV Lithography

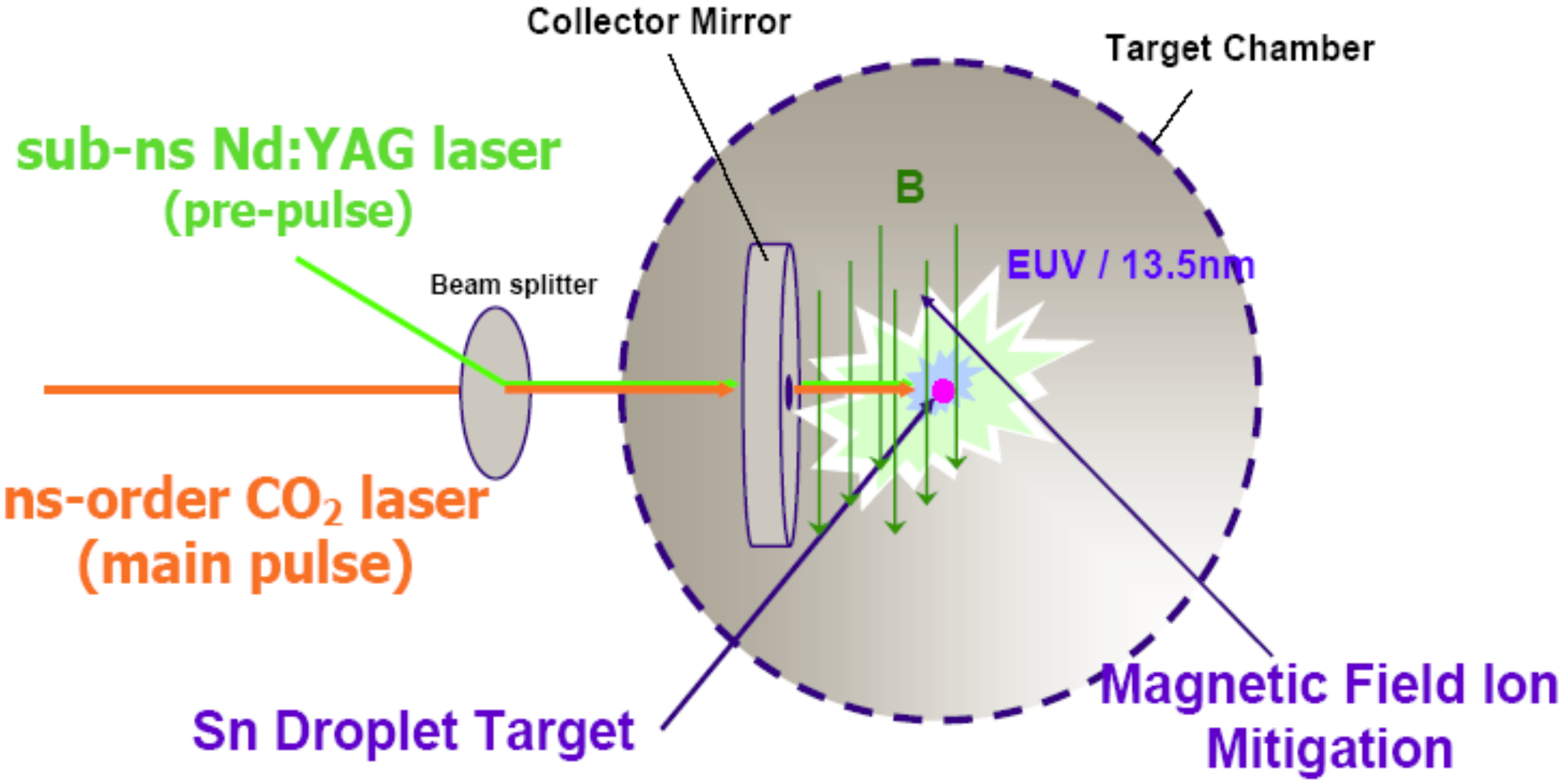


Discharge (DPP) source

V.M.Borisov, KSC
K.N.Koshelev, ISAN



Laser (LPP) source



Conversion Efficiency (CE) of
2.5 – 4.5 % has been achieved with Sn wire w/o pre-pulse

Code THERMOS

- Self-consistent Hartree-Fock-Slater potential at given temperature T and density ρ
- Ionization stage & ion composition
- Equation of state
- Absorption and emission coefficients
- Heat- and electro- conduction coefficients
- Rates of atomic processes

Range of substance parameters

Temperature T ~ $10^4 - 10^9$ K

Density ρ ~ $10^{-6} - 10^4$ g/cm^3

Material – from Hydrogen (Z=1) to Gold (Z=79)

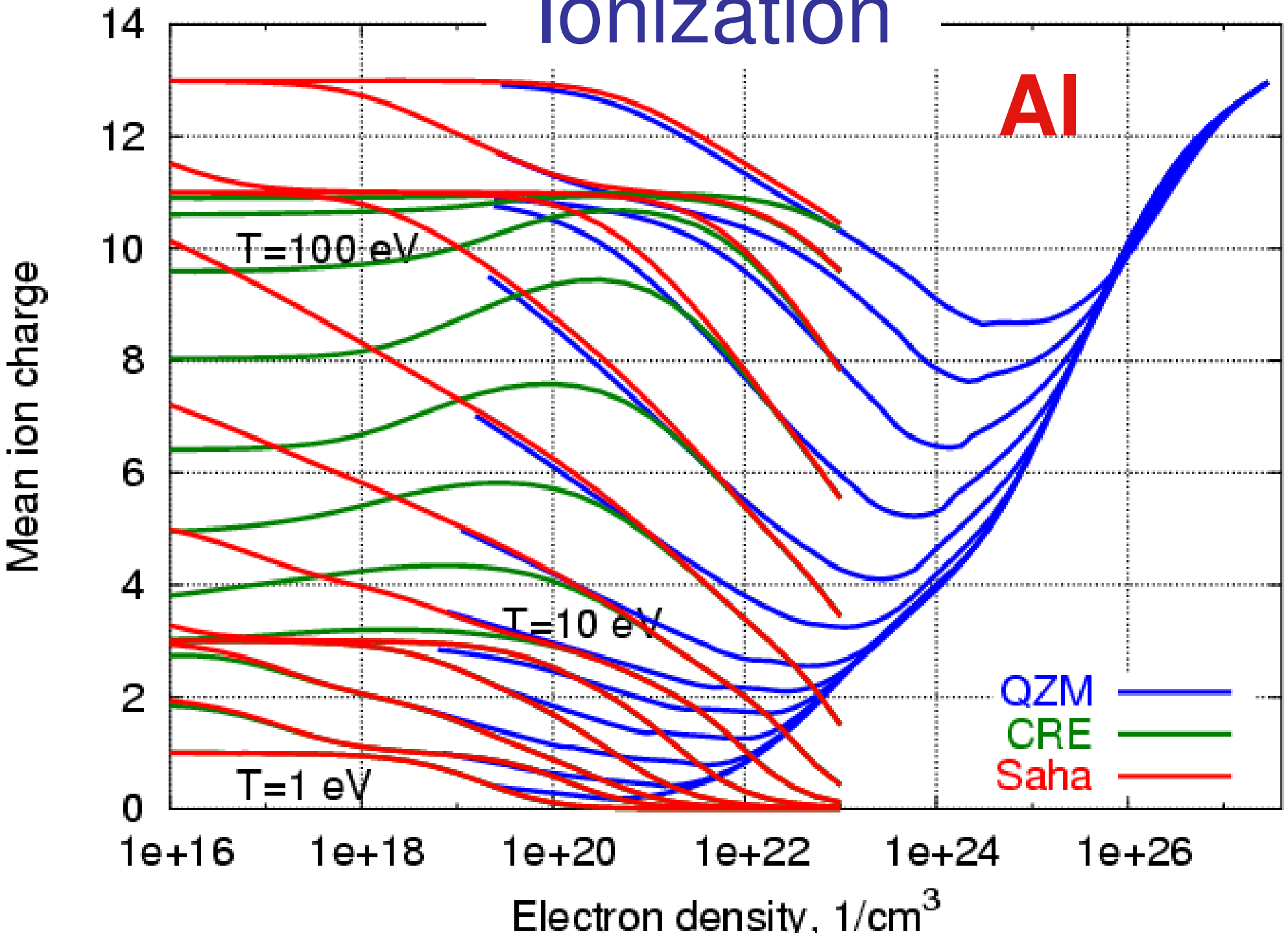
Benchmark

Opacity Workshops & Code Comparison Study
1992 – 1997

Non-LTE Code Comparison Workshops
1999 - 2009

Opacity experiments:
test the physics foundations
of the plasma models and codes also

Ionization


Al
T=100 eV
T=10 eV
T=1 eV
QZM
CRE
Saha
Mean ion charge
Electron density, 1/cm3
0
2
4
6
8
10
12
14
1e+16
1e+18
1e+20
1e+22
1e+24
1e+26

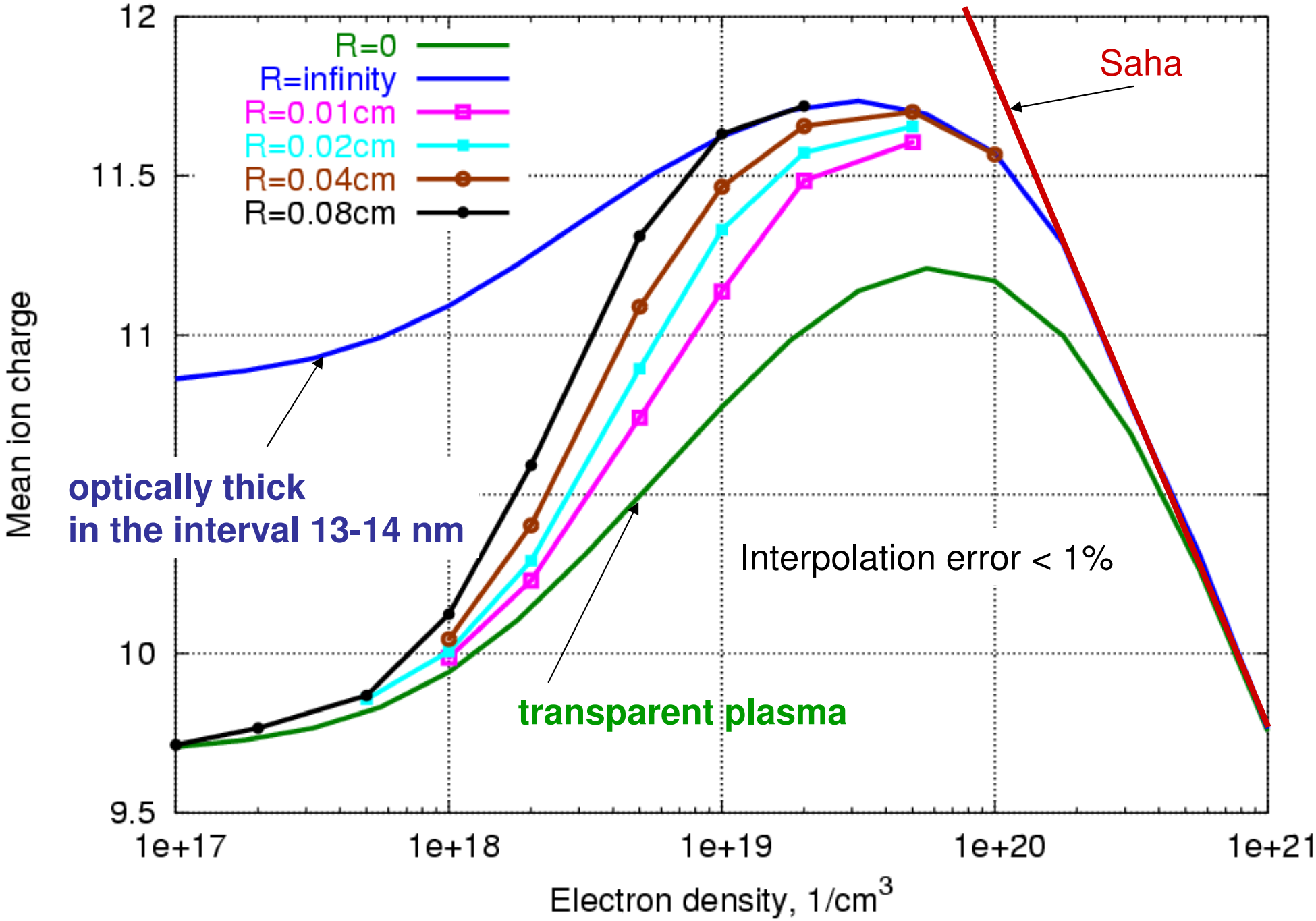
Simple solution for RMHD codes!

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

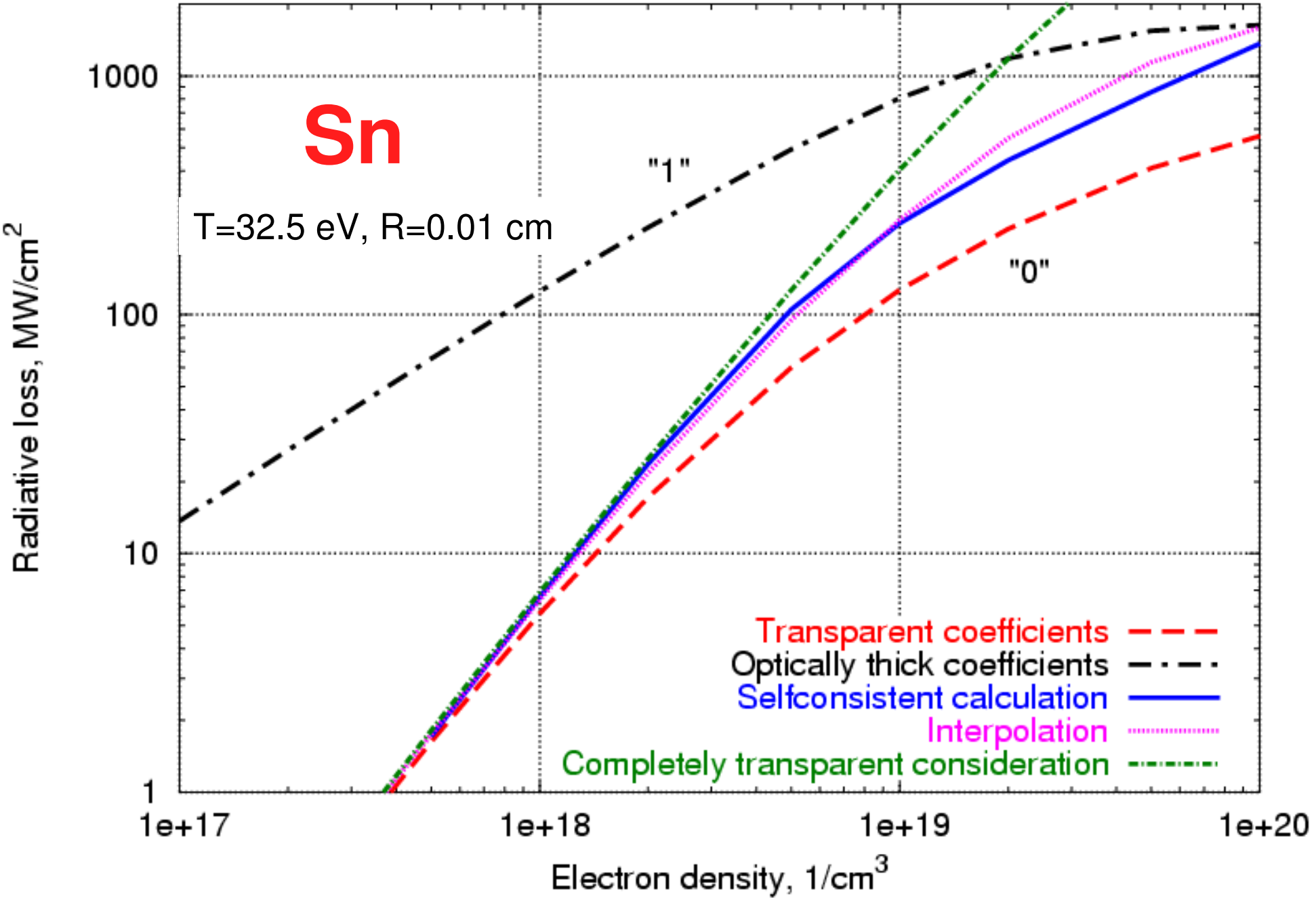
Opacity effects are included by using effective total escape parameter ξ, which is equal 1 for transparent case and equals 0 for optically thick case.

Sn

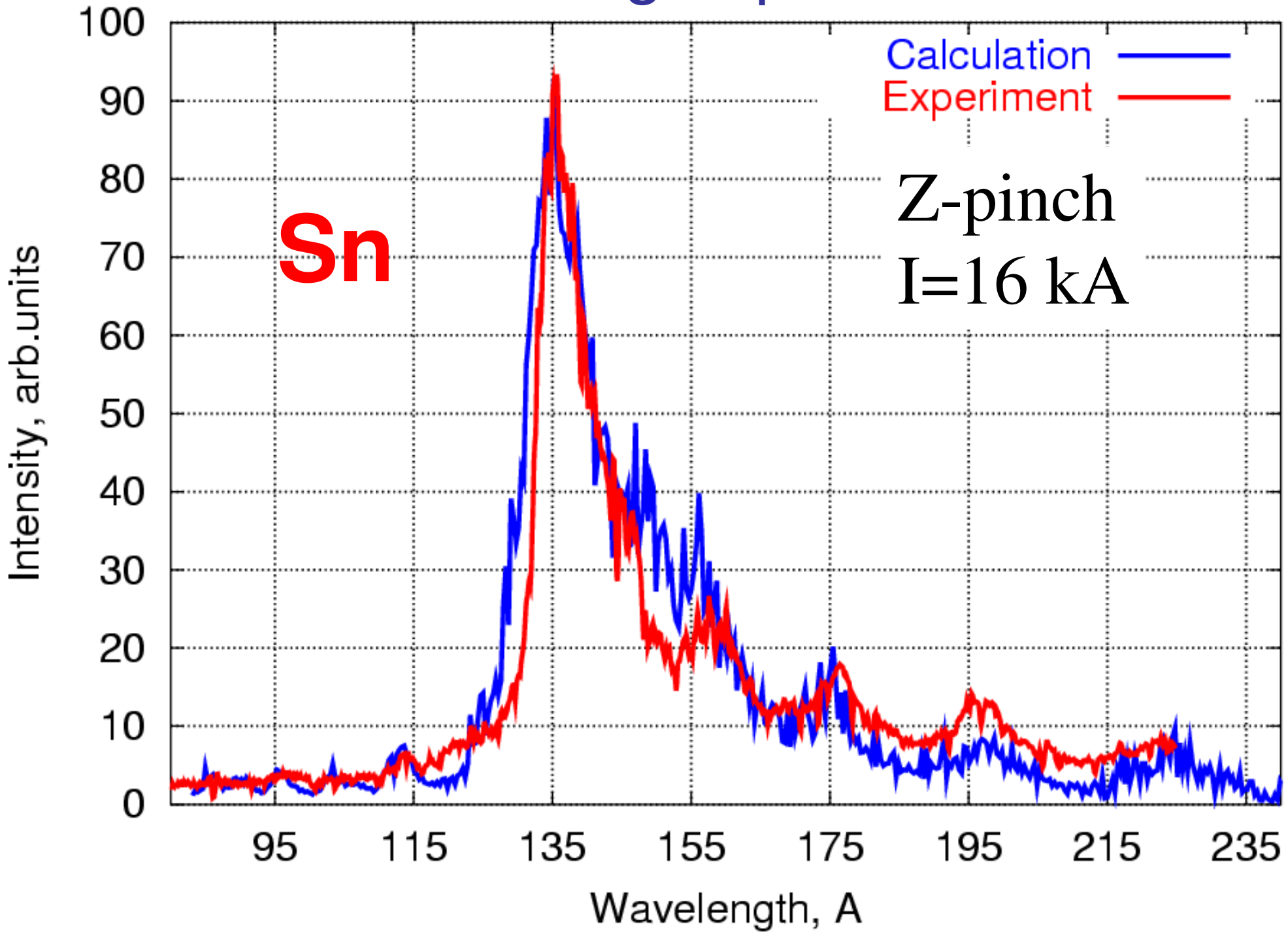
Ionization: T=32.5 eV



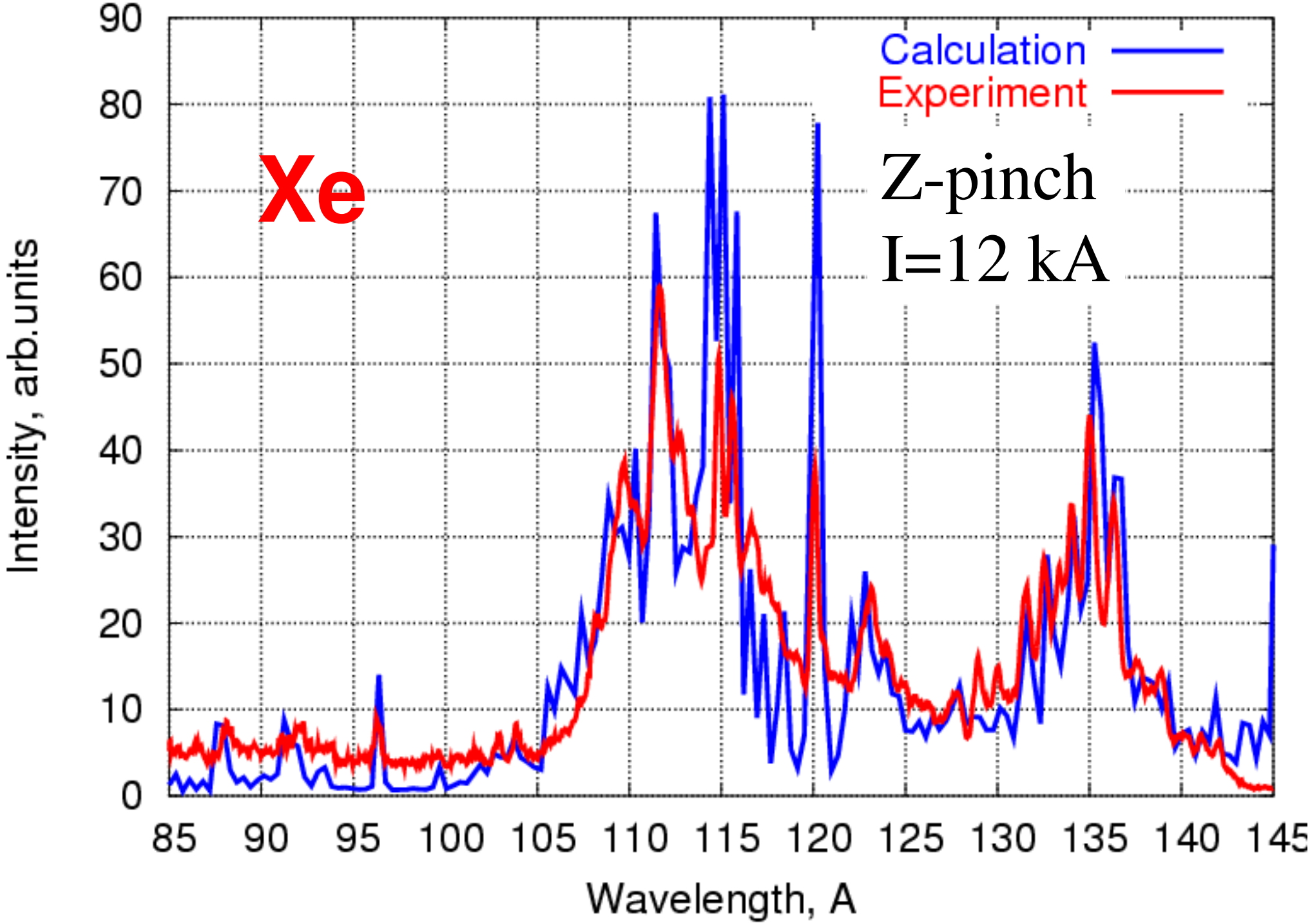
Radiative loss
detailed calculation & interpolation



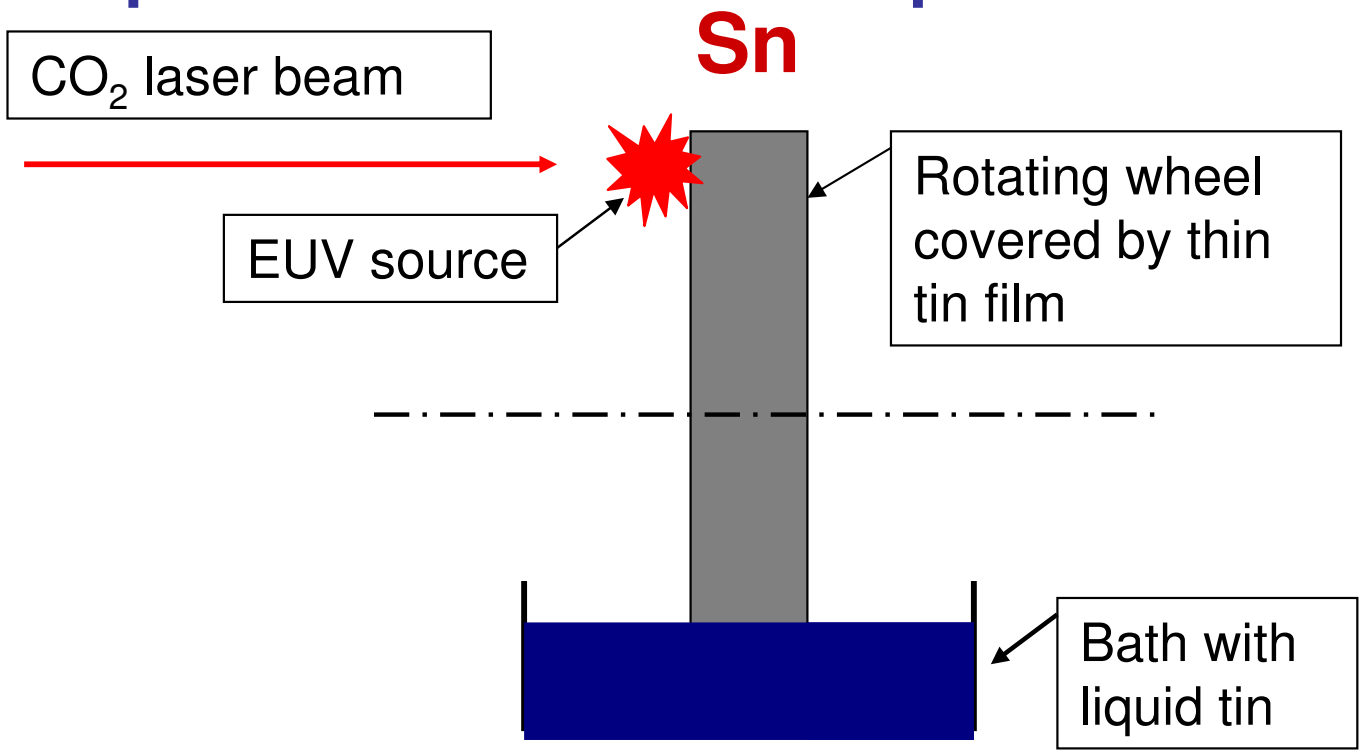
Tin discharge spectrum



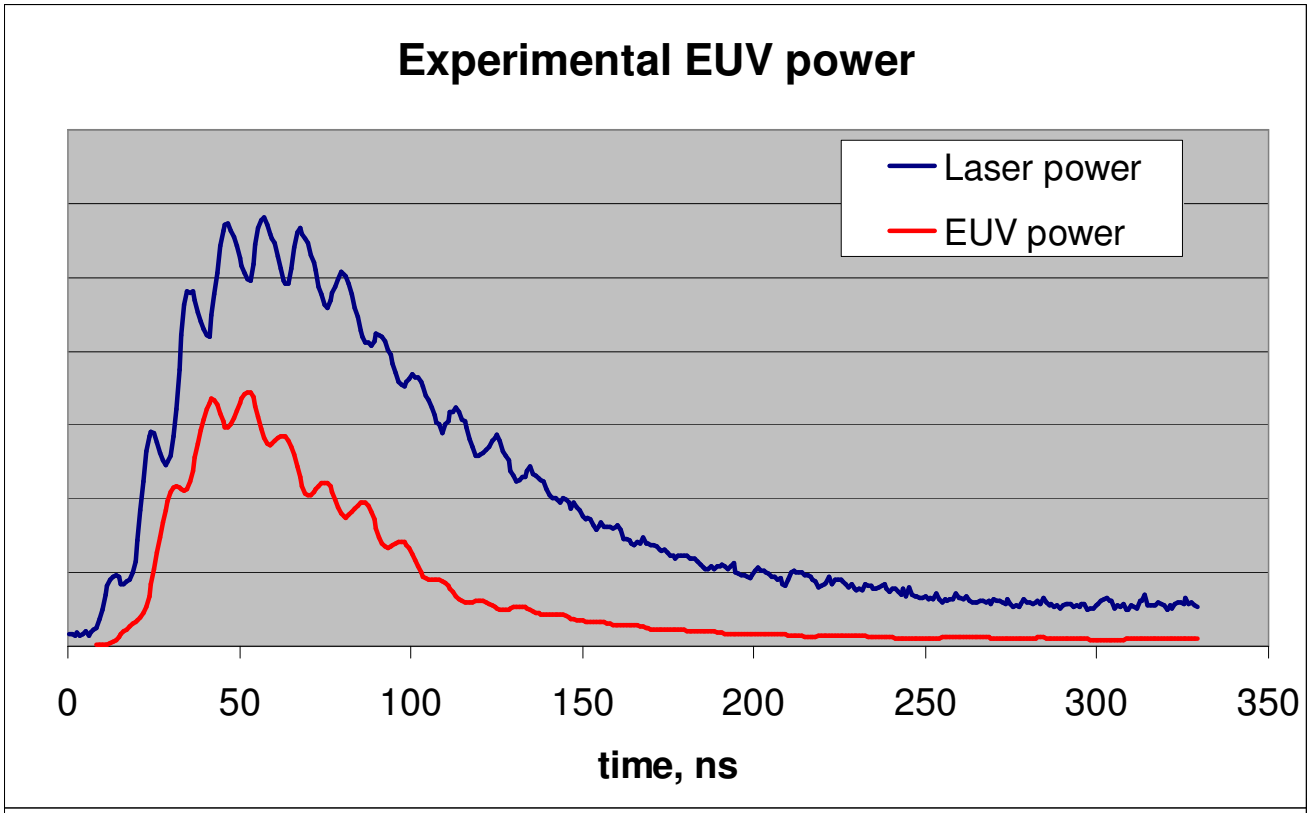
Xenon discharge spectrum

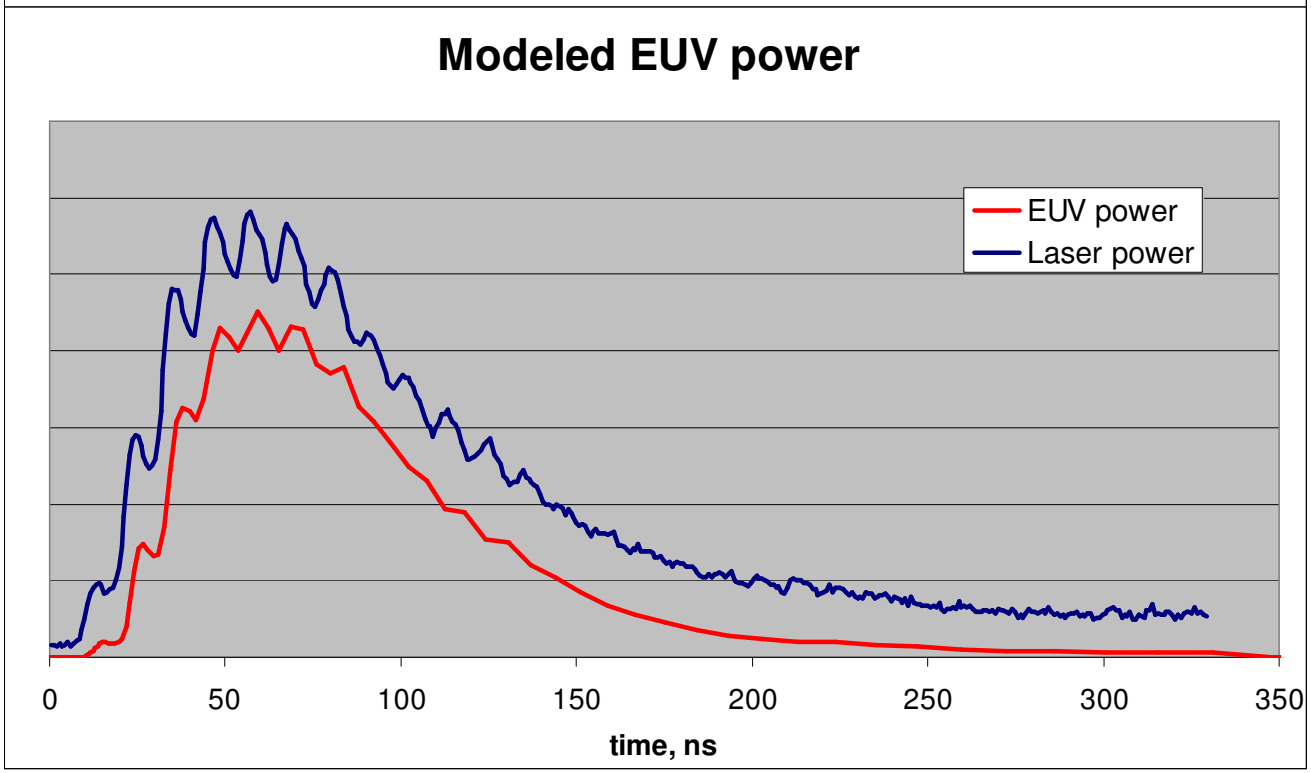


Laser source: comparison with experiment

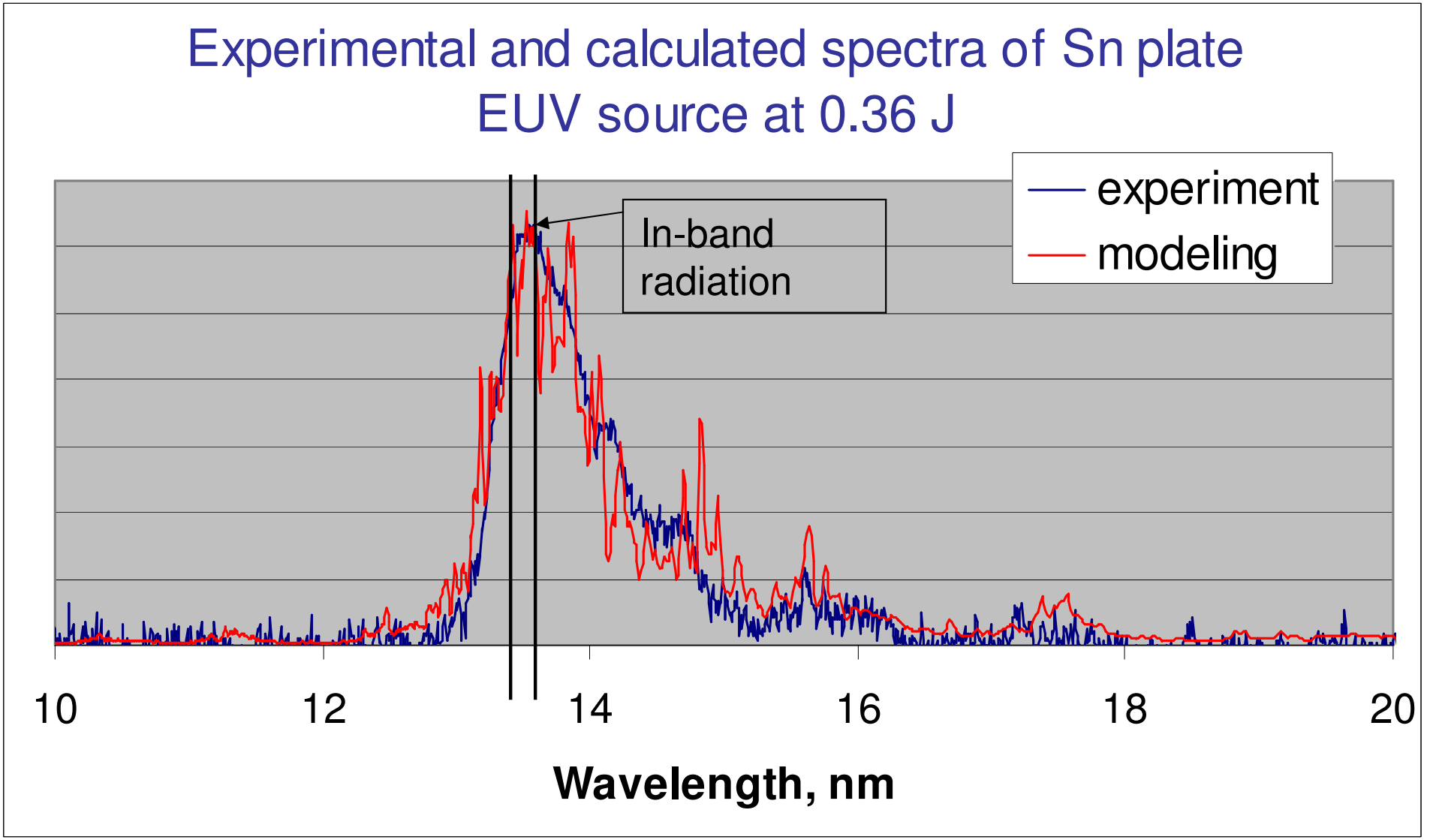


- CO_2 laser beam energy was 0.36 J
- Radial distribution of laser power density close to Gaussian with size 300 μm ($1/e^2$)
- Temporal dependence will be shown later
- Experimental data on EUV source spectra, EUV power, EUV isotropy, EUV source size were used for comparison with calculated results





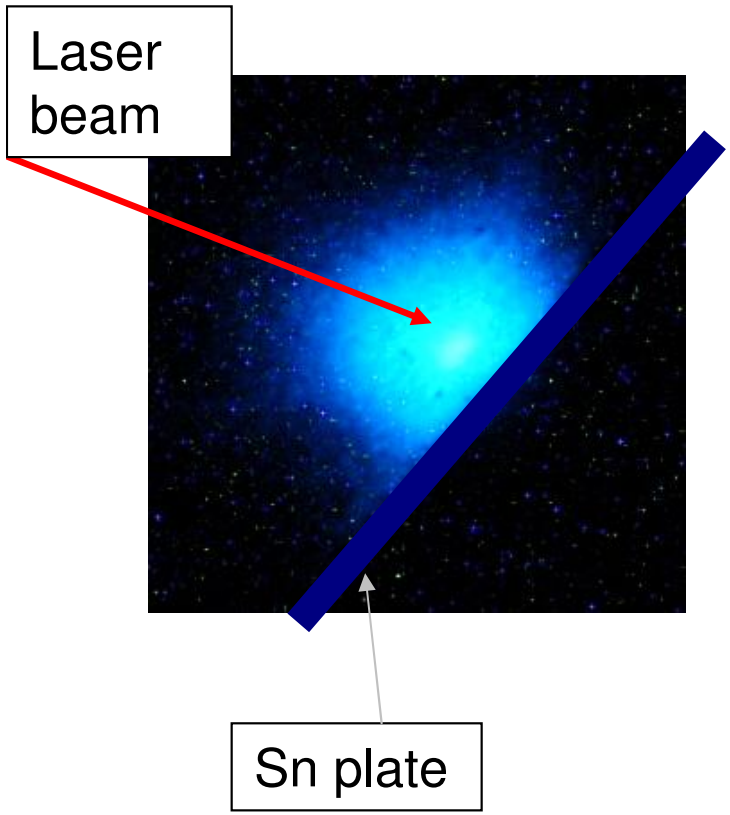
1. Calculated time dependence of in-band EUV power repeats qualitatively its experimental behavior
2. Experimentally seen long tail of EUV radiation was modeled as well
3. In band EUV repeats laser pulse waveform with delay ~ 3-5 ns



1. Experimental and calculated spectra coincide rather well
2. Other spectral regions were calculated too, though without details. Only negligible part of energy was emitted there ~< 1%
3. Smooth character of experimental spectra near in-band region is

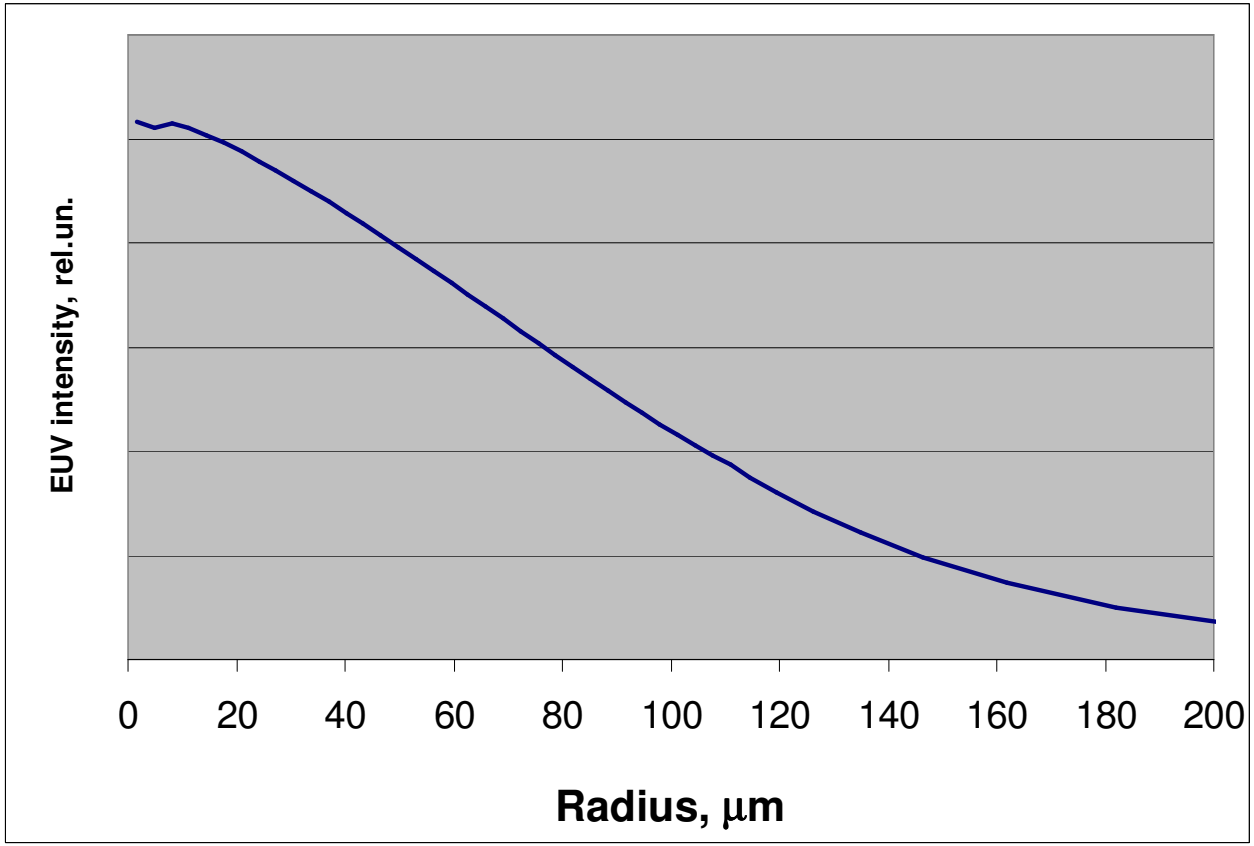
EUV source size

Experiment



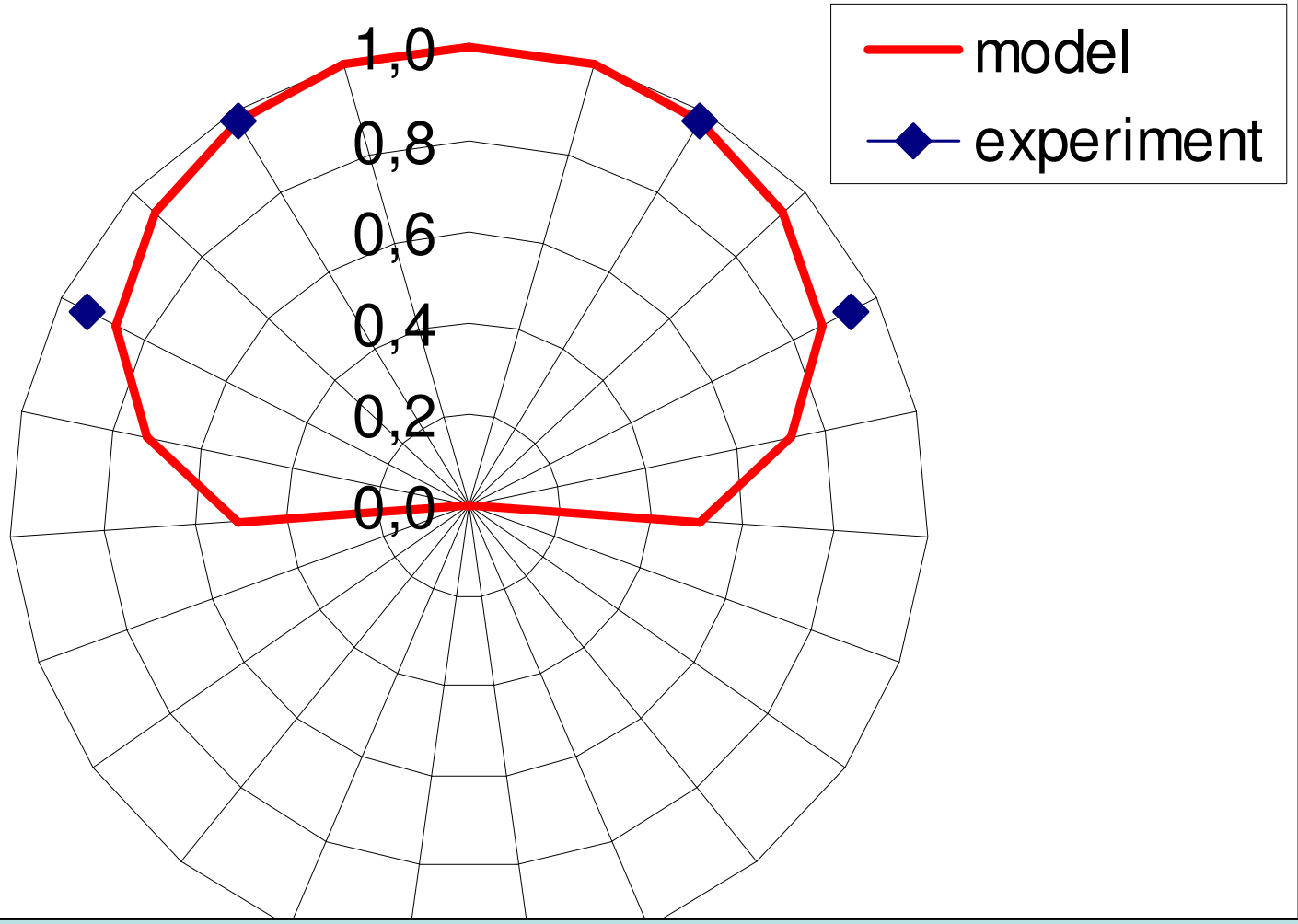
Pinhole image gives EUV source size about 300 μm (1/e²)

Modeling



1. EUV source size, D = 2*R is about 350 μm (1/e²), which is close to experimental one
2. EUV source size is defined mainly by laser focus spot size
3. It slightly increases with laser energy

Source isotropy



1. Vertical direction, polar angle θ = 0, corresponds to direction of laser
2. Isotropy of EUV source is comparatively high in 5 steradian of collector mirror
3. Experimental EUV isotropy is slightly higher than calculated one

CONCLUSION
Code THERMOS_BELINE

for modeling EUV emission spectra

- self-consistent calculation of level kinetics and radiation transport for different plasma configurations

- Al, W, Sn, Xe and other elements (admixture of H, He, C, O)

- Tables for RMHD codes

- Spectra resolved in time and space (postprocessing)