Performance Evaluation on Discharge & Laser based EUV Sources using Z* 2-D Radiation MHD Modelling

RISING ABOVE THE CHALLENGE

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S.V. Zakharov *, P. Choi, C. Dumitrescu

zakharov@eppra.org *EPPRA SAS, Courtaboeuf, France*

V.G. Novikov

KIAM RAS, Moscow, Russia

A.Yu. Kroukovski *

IMM RAS, Moscow, Russia

K.D. Ware

ER2S inc., San Diego, CA, USA

* *also with SSC RF TRINITI, Troitsk, Russia*

European Pulsed Power Research

in association with

ER2S, Inc.

Environment Remediation Solutions and Systems

Abstract

Z* is a 2-D radiation MHD code specifically developed at EPPRA to model industrial plasmas, taking into account details of plasma surface interaction and radiation emission and absorption, through a dedicated equation of state solver. Spectral details of the radiation output is computed.

Here we present applications of Z* in the development of EUV sources.

A) a DPF and CD discharge sources - The aim is to better understand the in-band EUV and out of band radiation as a function of operating pressure, in an admixture of Xe or Kr with He. For a given driving condition, the results show that there is a fairly narrow range of pressure when the EUV radiation is maximized though the % of the in-band radiation out of the total radiation. The effect of LTE and non-LTE are highlighted.

B) a laser target source - The aim is to compare the radiation properties of Xe and Sn as EUV radiators. The suitability of Xe based EUV sources has been under close examination. The measured energy conversion efficiency is below 0.5 % at the 13.5 nm regime. Sn has been suggested as an alternative with a significantly higher conversion efficiency. Here we present the first calculation with Z*, on the EUV radiation conversion efficiency of Sn with different laser energy, taking into account details of plasma surface interaction and radiation emission and re-absorption. The result is compared with both solid cryogenic Xe and Xe gas jet targets.

OUTLINE

- Simulation Code Z*
- Xenon radiation properties
- Dense Plasma Focus (DPF) discharge source
- Hollow-Cathode Triggered Capillary Discharge (CD) dynamics
- Laser heated Sn & Xe targets
- Summary

CODE Z*

Pre-processor THERMOS

LTE, non-LTE tables, EOS of complex ion compositions

- plasma kinetic coefficients
- detailed spectral radiation coefficients (opacity, emissivity)

Core-processor ZERMHD

2D RMHD with finite conductivity and displacement current

- 2D cylindrically symmetric geometry; (r, φ, z) field components
- plasma & solid dynamics, Lagrange-Euler fully conservative scheme
- multi-group radiation transport, non-equilibrium

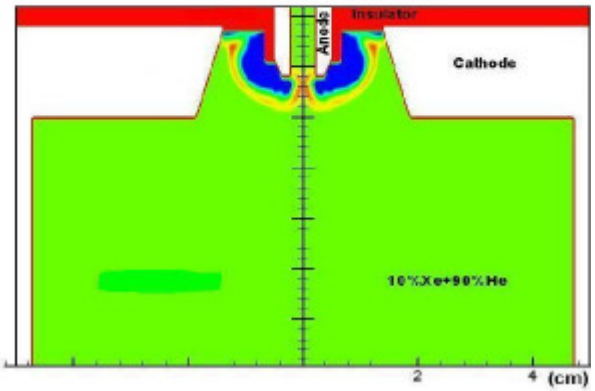
Post-processor RAY

3 dimensional radiation transport

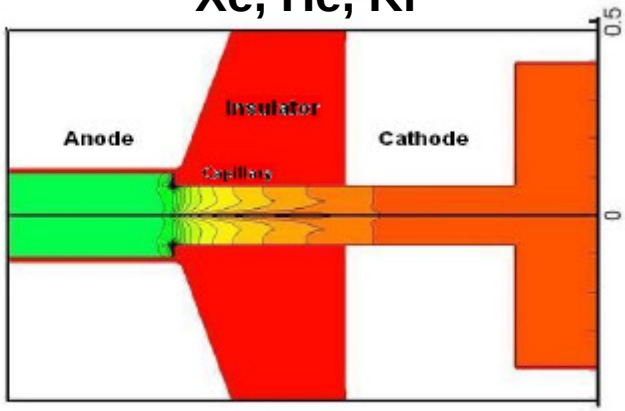
- detailed X-ray spectra

Z* Benchmarks

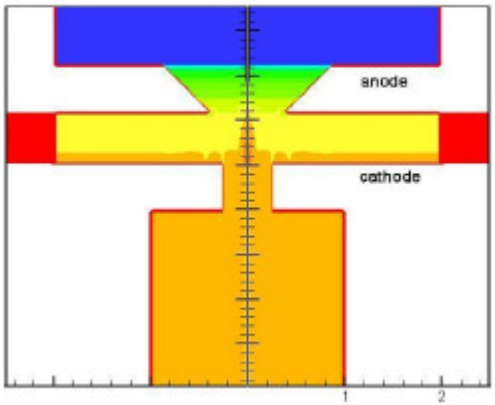
· **Dense Plasma Focus**
Xe, He



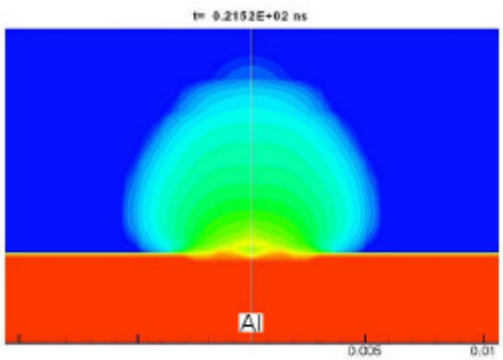
• **Capillary Discharge**
Xe, He, Kr

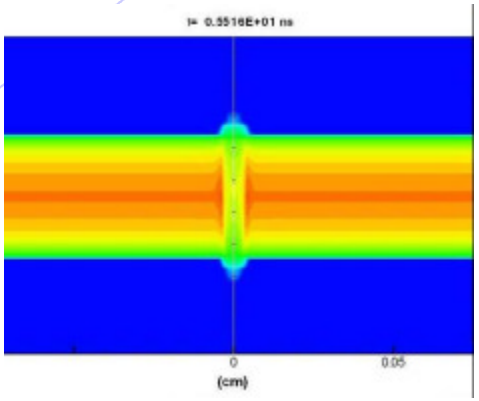


• **Hollow cathode**
Z-pinch: Xe, O

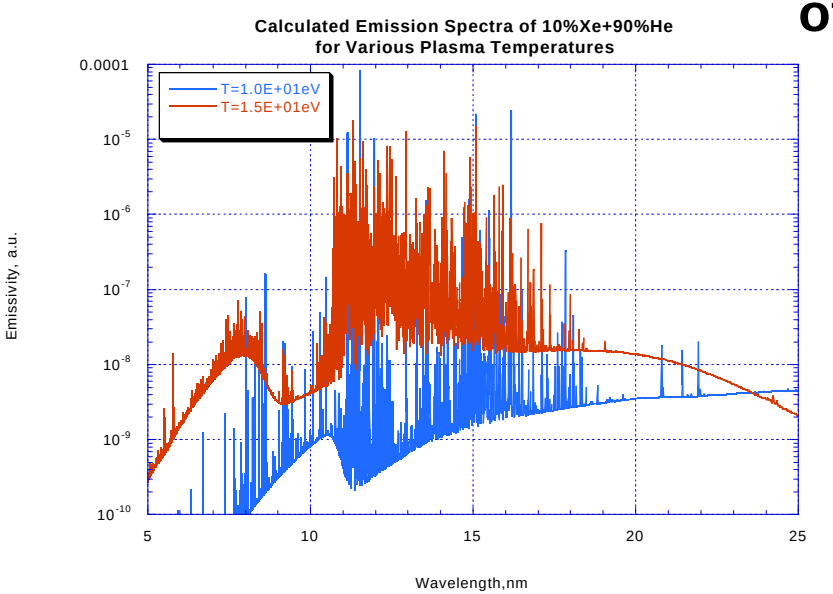


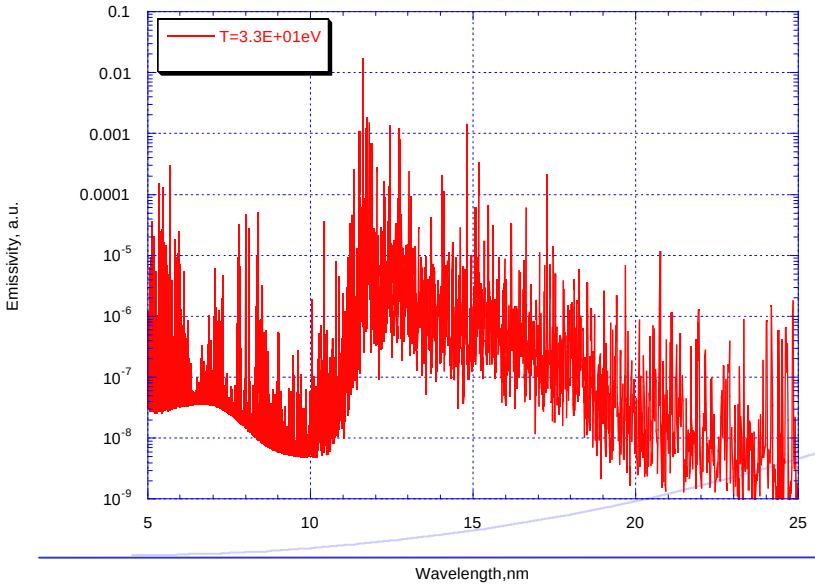
· **Laser produced plasma:**
Al, Xe, Sn



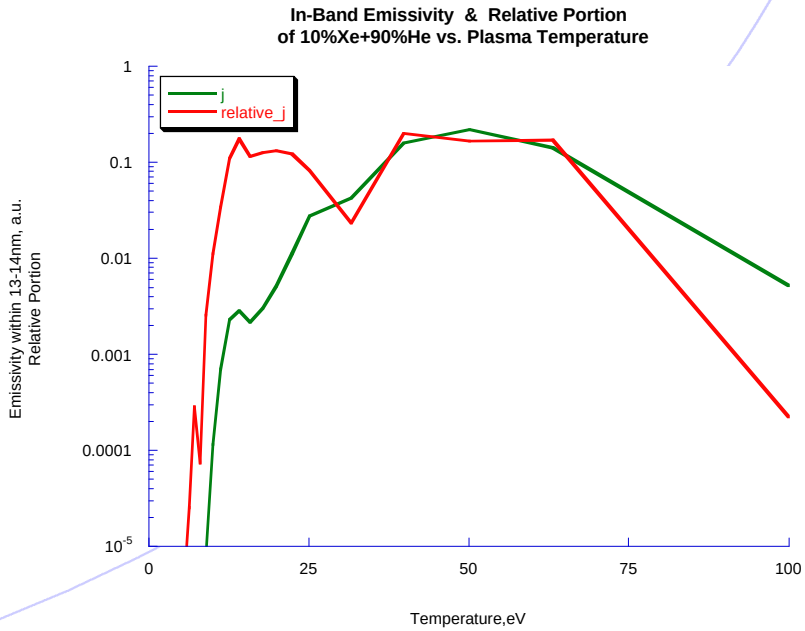


Radiative Properties
of 10%Xe+90%He



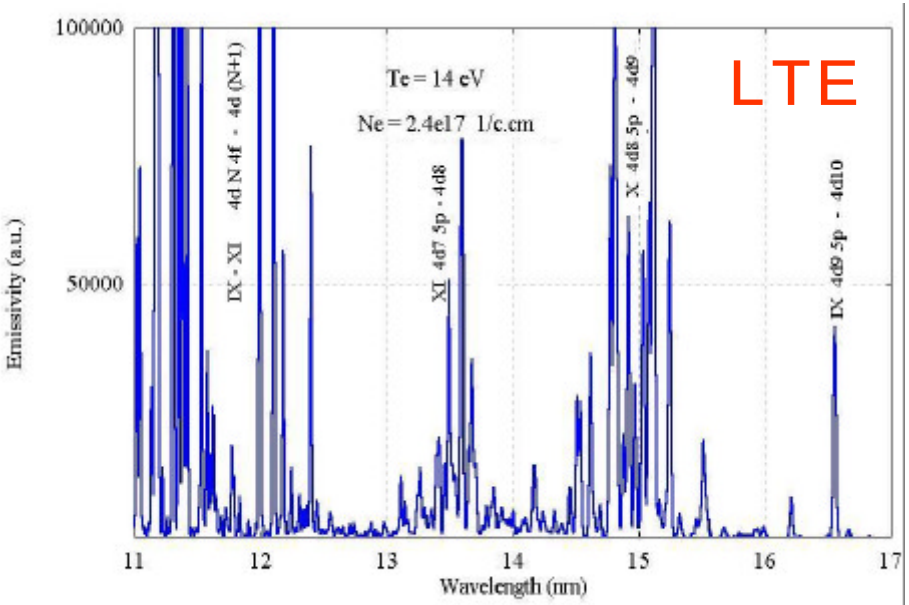


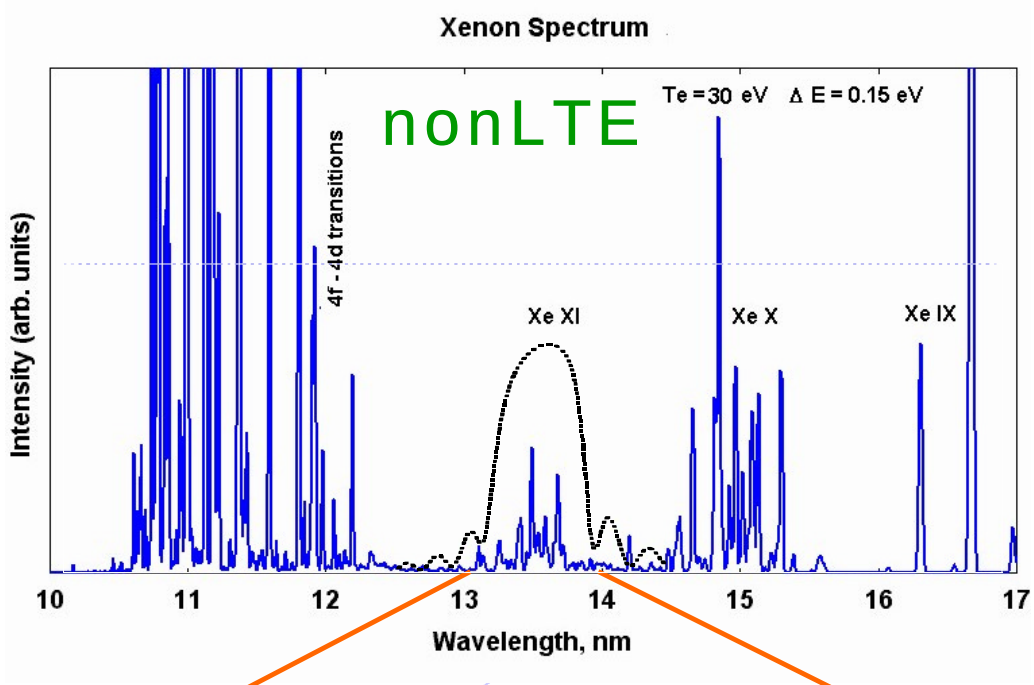
Flash and burning-out of ionisation states define in-band emission efficiency of xenon plasma



EUV emission efficiency examination

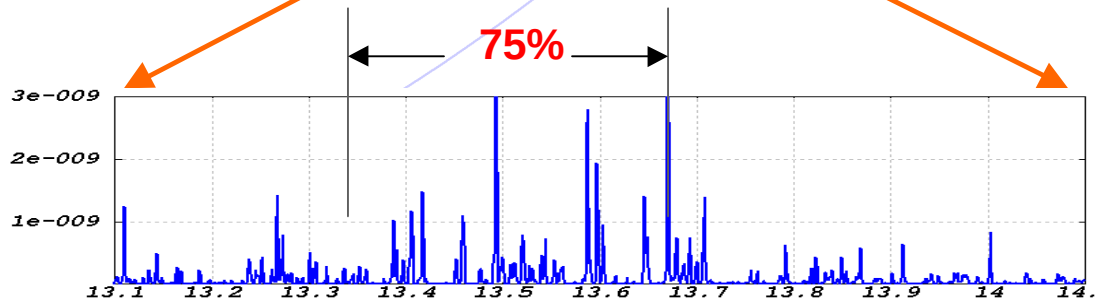
Calculated Emission Spectra of ionized Xe



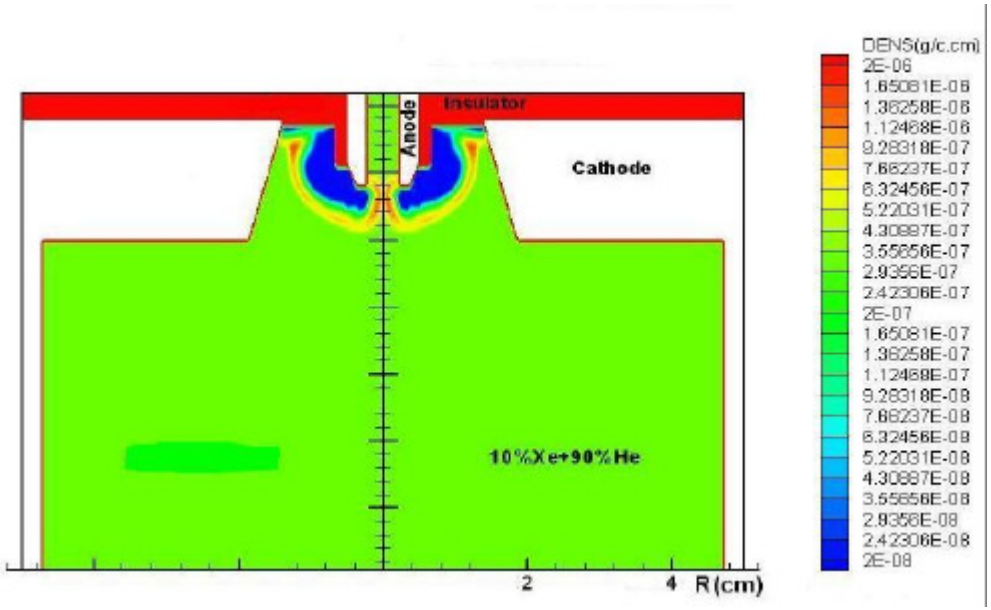


Detailed term accounting in intermediate coupling scheme approximation

Clusters of 10^5 spectral lines



Dense Plasma Focus



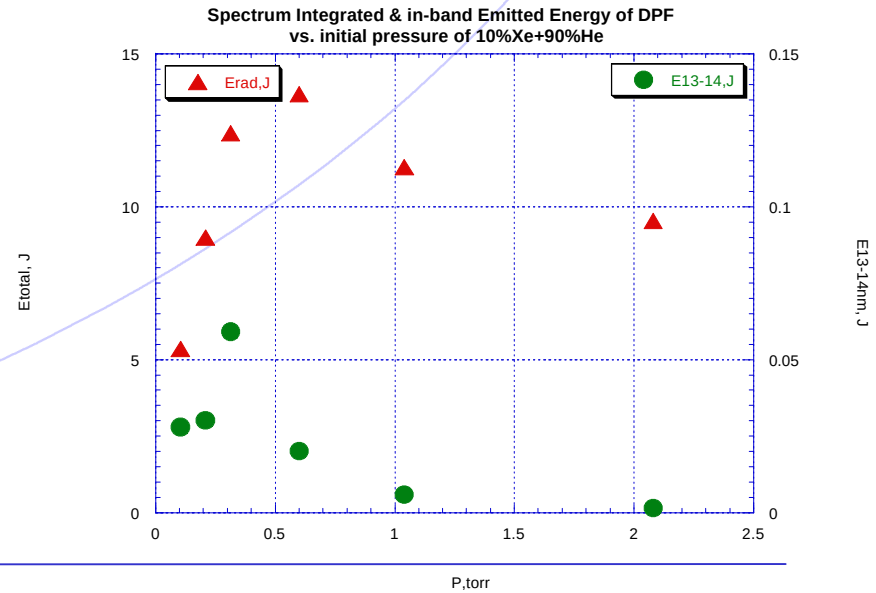
DPF radiation source features

EUV (13-14nm) emission	60mJ
EUV emission efficiency	0.5%
Fast motion of emitting object	10^7cm/s
Ablation of anode	12J/cm^2
and insulator	1.1J/cm^2

Power Source

Charge energy	29J
Current	70-80kA
Pulse	150ns

Gas: 10-1%Xe+90-99%He
Pressure: 0.1-1Torr

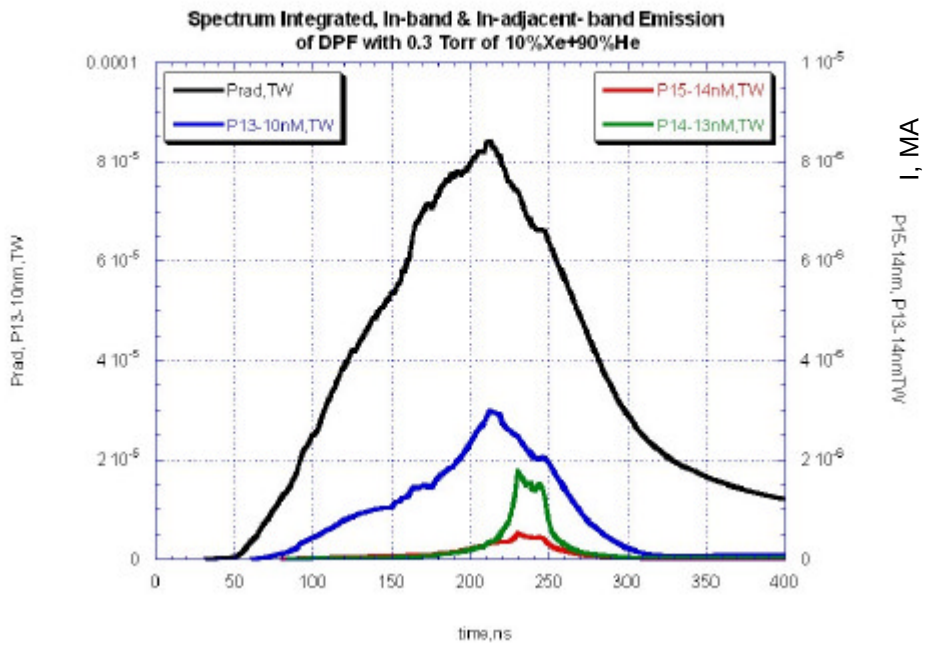


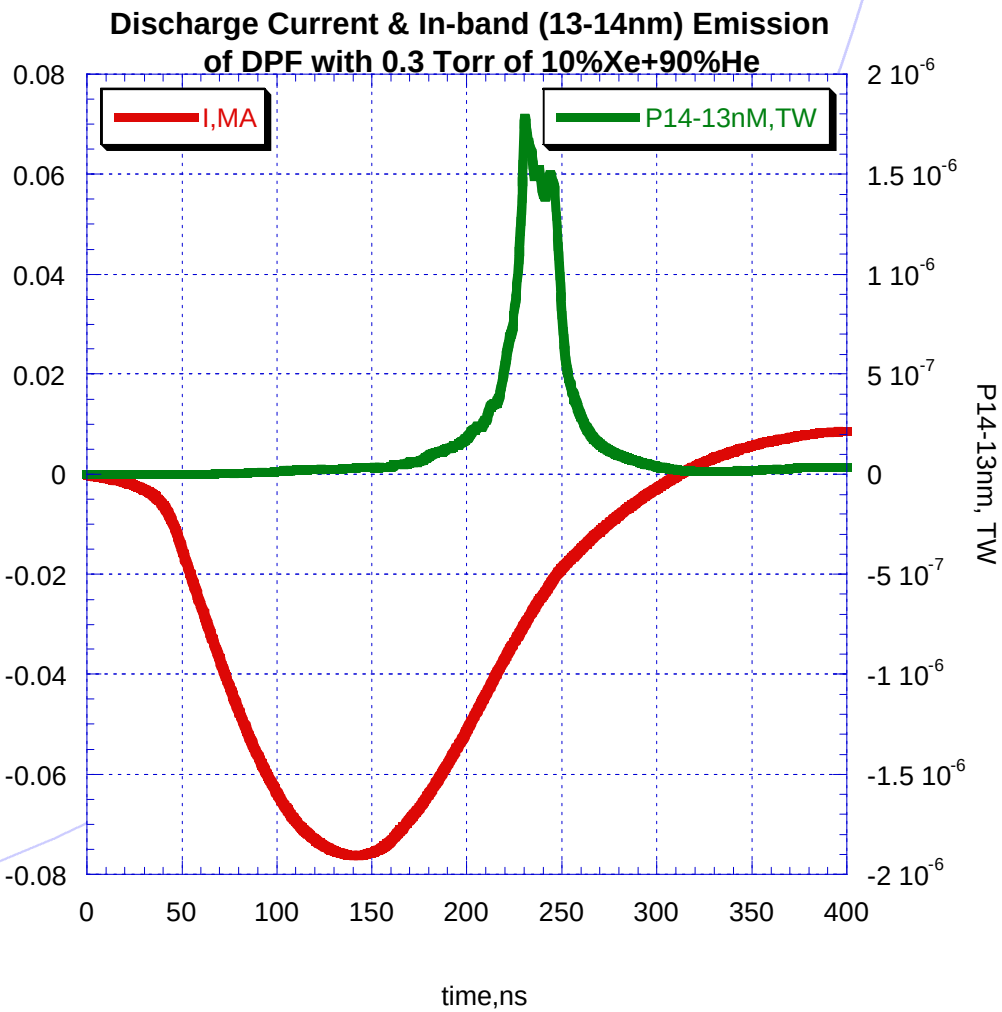
Calculated DPF Emission

10%Xe+90%He, 0.3 Torr

Full non-LTE modeling

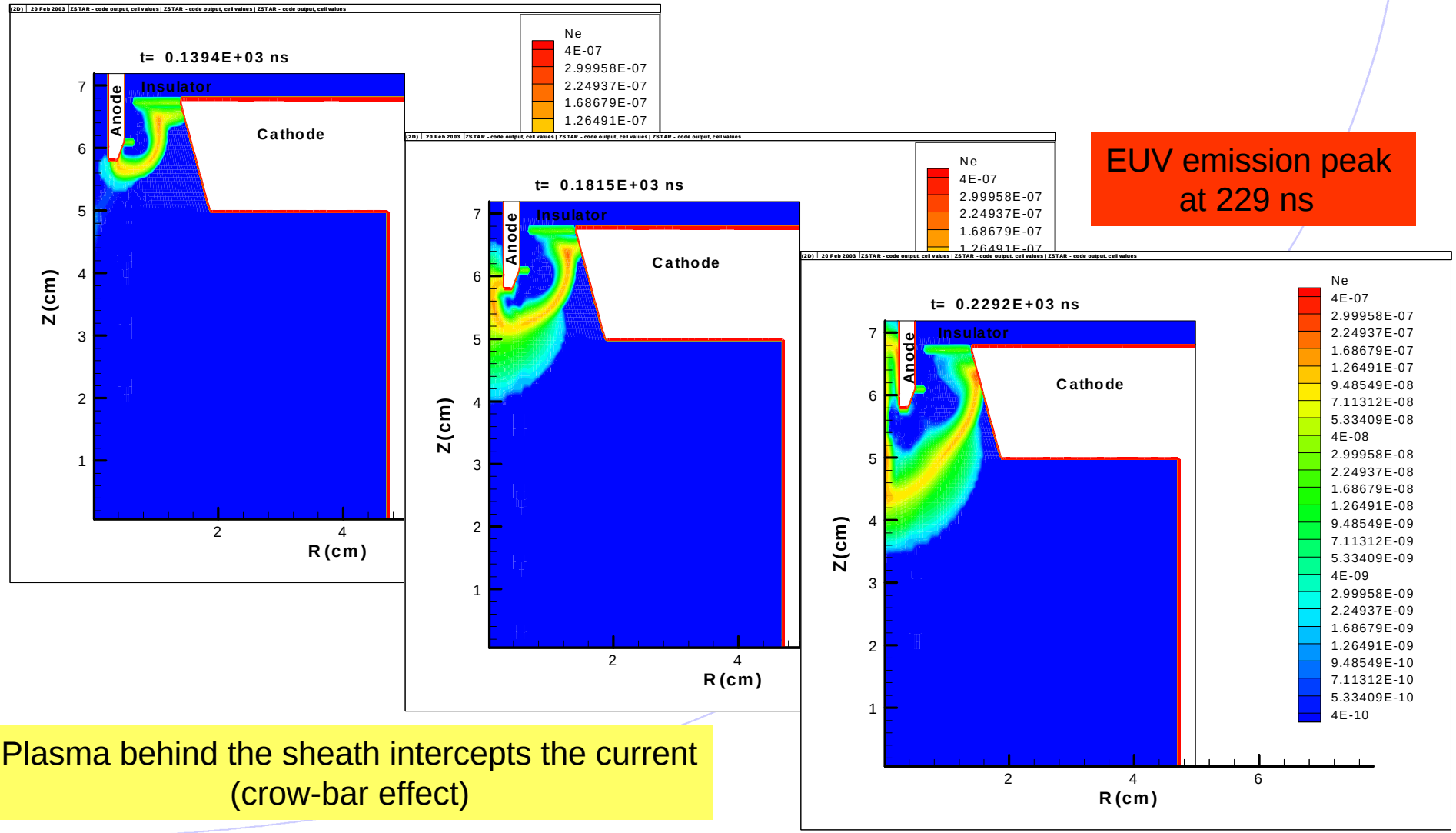
with radiation transport





Dynamics of DPF

with 0.3 Torr of 10% Xe+90%He

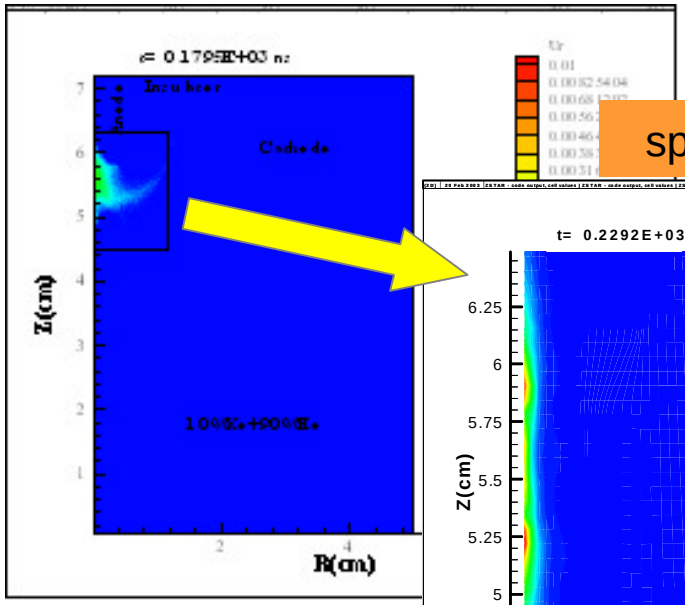


EUV emission peak at 229 ns

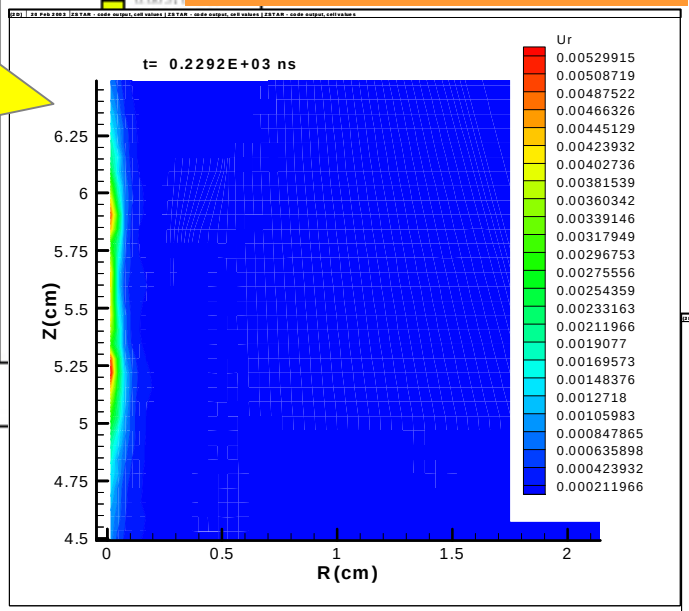
Plasma behind the sheath intercepts the current (crow-bar effect)

Radiation Source

of DPF with 0.3 Torr of 10% Xe+90%He

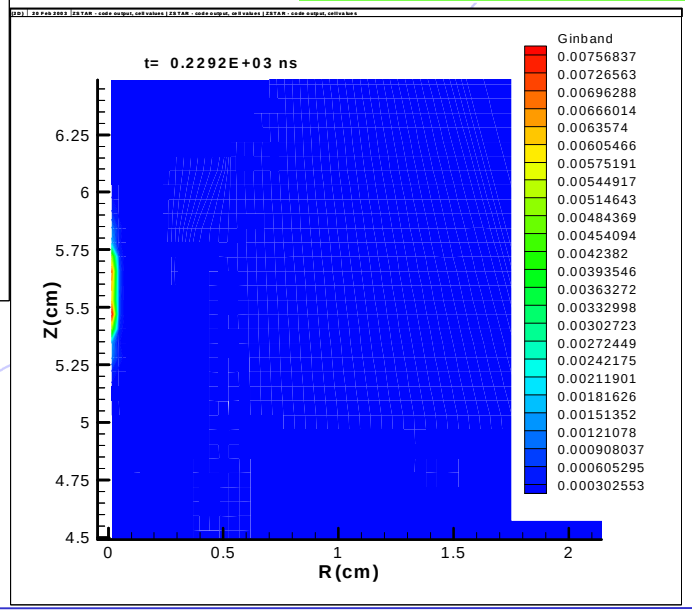


spectrum integrated



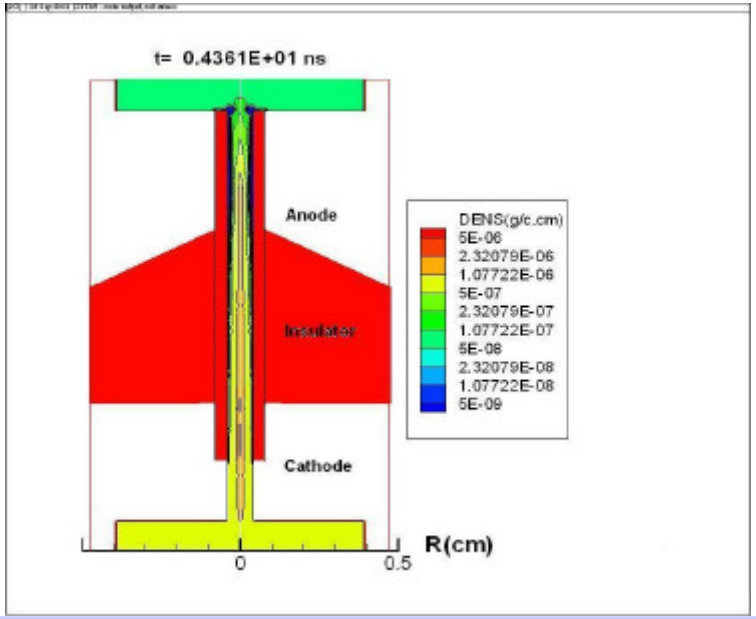
zoomed pictures
at EUV peak

in-band 13-14nm



Absolutely different images
in total and EUV light

Hollow-Cathode Triggered Capillary Discharge



CD radiation source features

EUV (13-14nm) Emission 0.1mJ/shot

Low physical instability

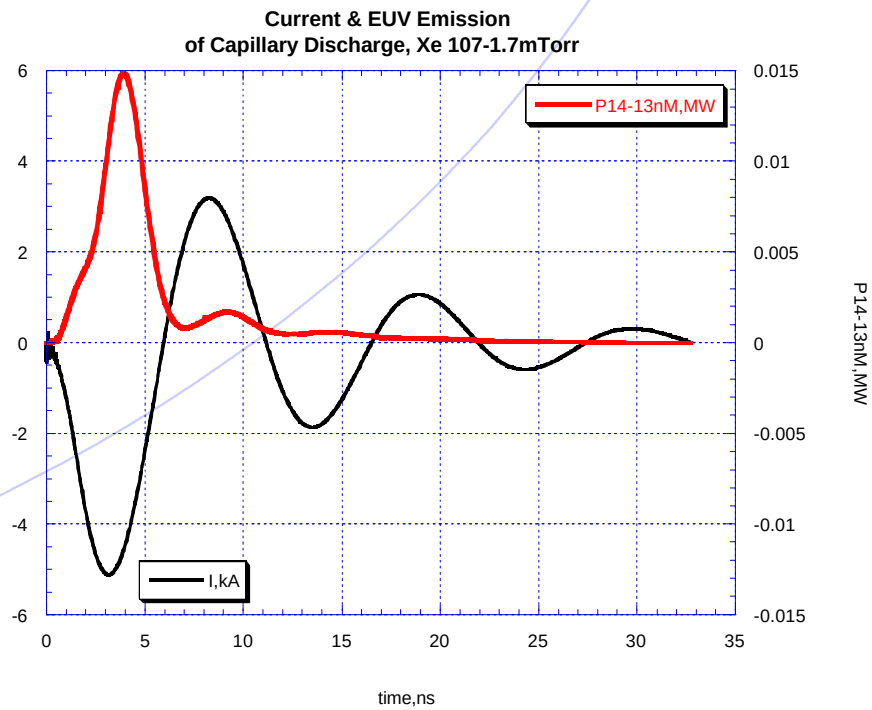
Density & Temperature control

Ablation of capillary

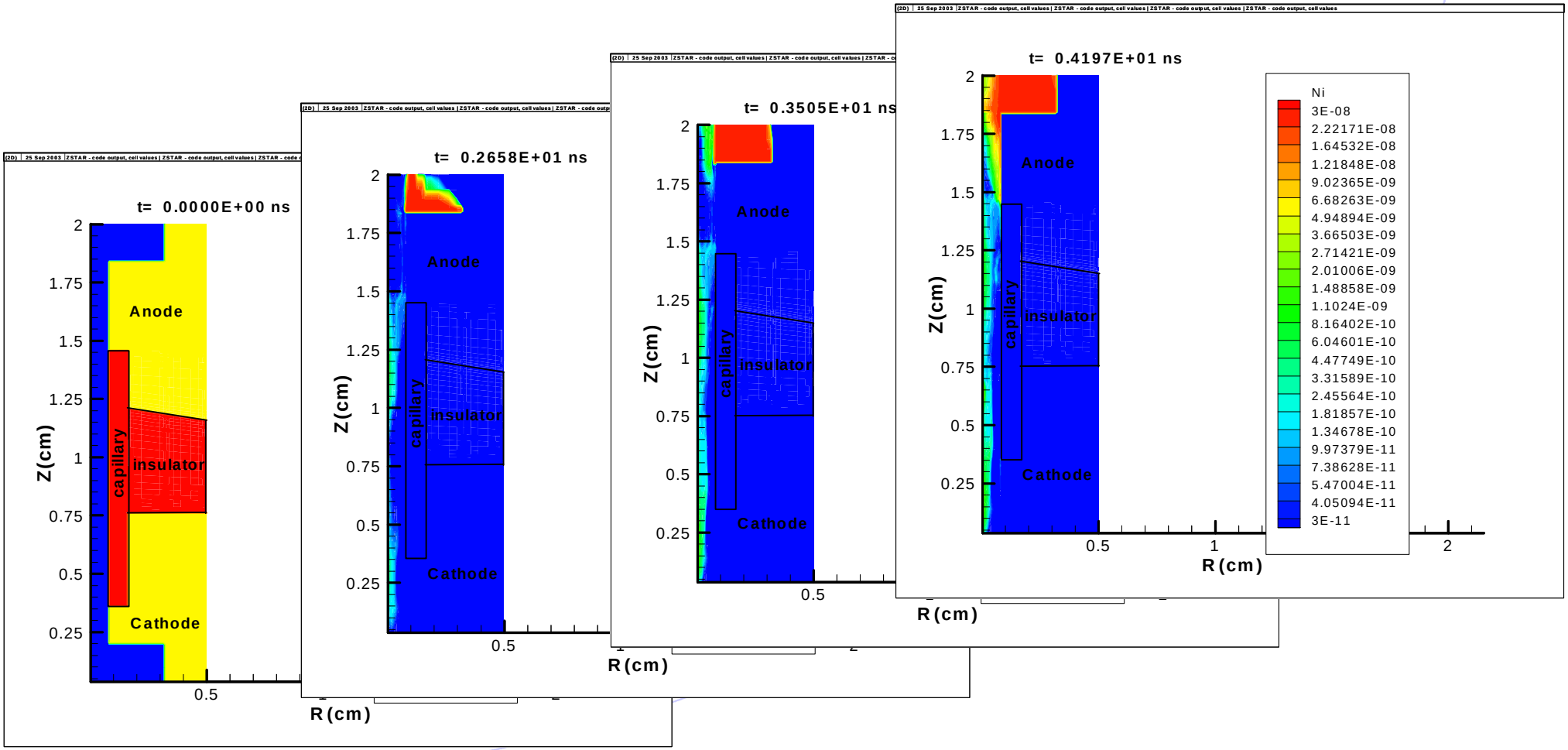
Power source

Charge energy	80 mJ
Current	3 - 6 kA
Pulse	6 ns
Capillary dimension:	∅ 0.8-1.6mm L= 6-12mm

Gas: 0.001-1Torr: Xe, ~10%Xe+90%He
Kr, ~10%Kr+90%He

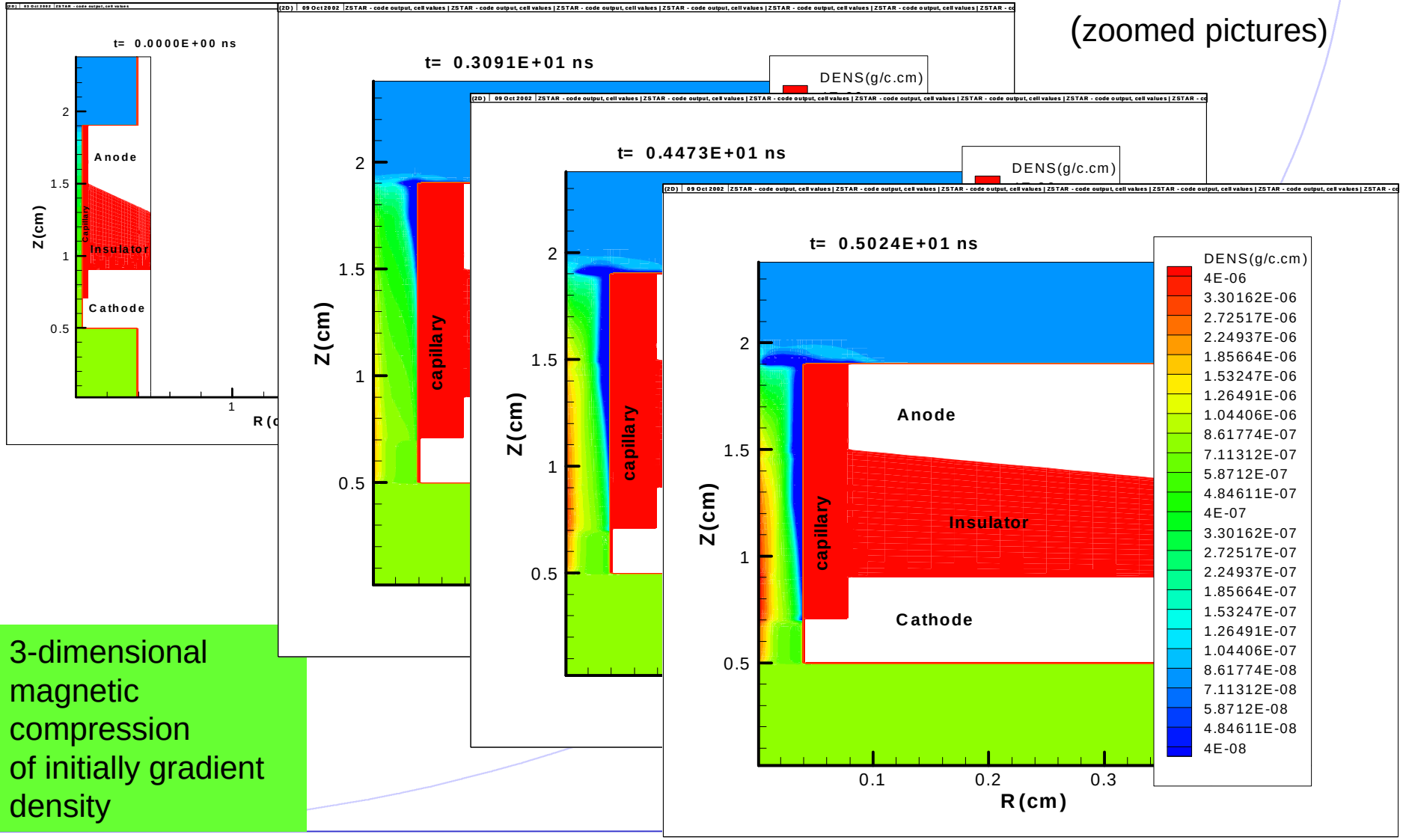


Ionization Wave in Capillary Discharge



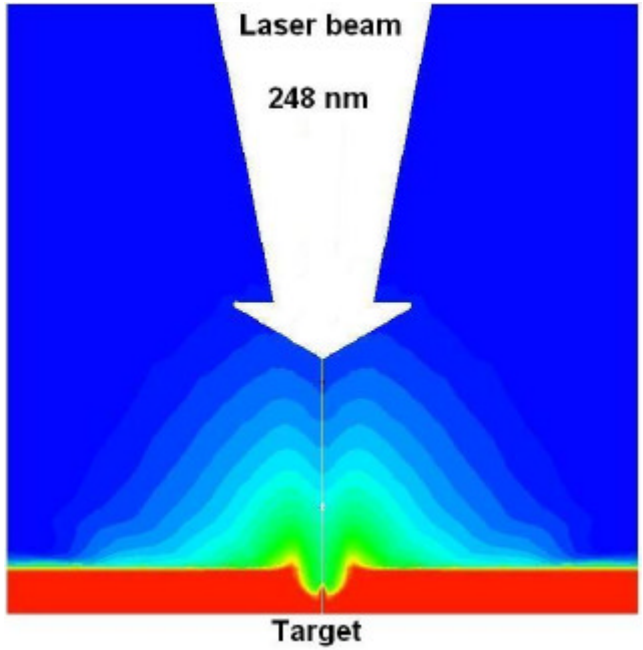
Capillary Discharge Dynamics
with 10% Xe+90%He

(zoomed pictures)



3-dimensional magnetic compression of initially gradient density

Laser Produced Plasma RHD Simulations



Laser

Energy	10mJ - 1J
Focusing	~500μ²
Pulse	~10ns

Target

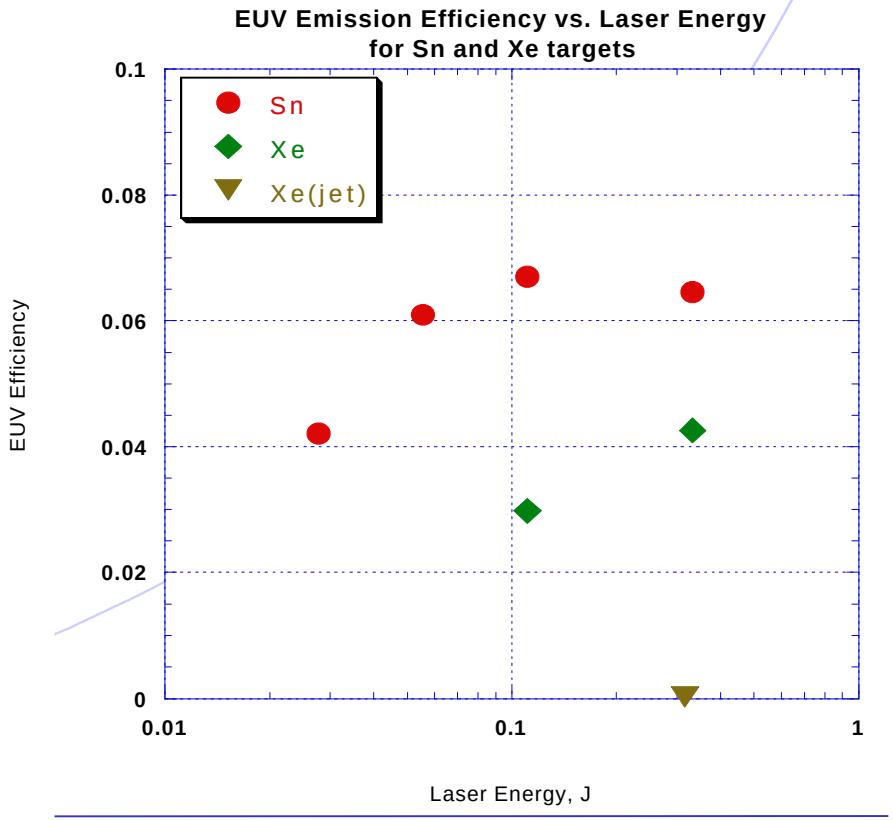
Sn solid

Xe cryogenic

or supersonic jet

LPP EUV source

EUV (13-14nm) efficiency Sn	7.5%
cryogenic Xe	4.5%

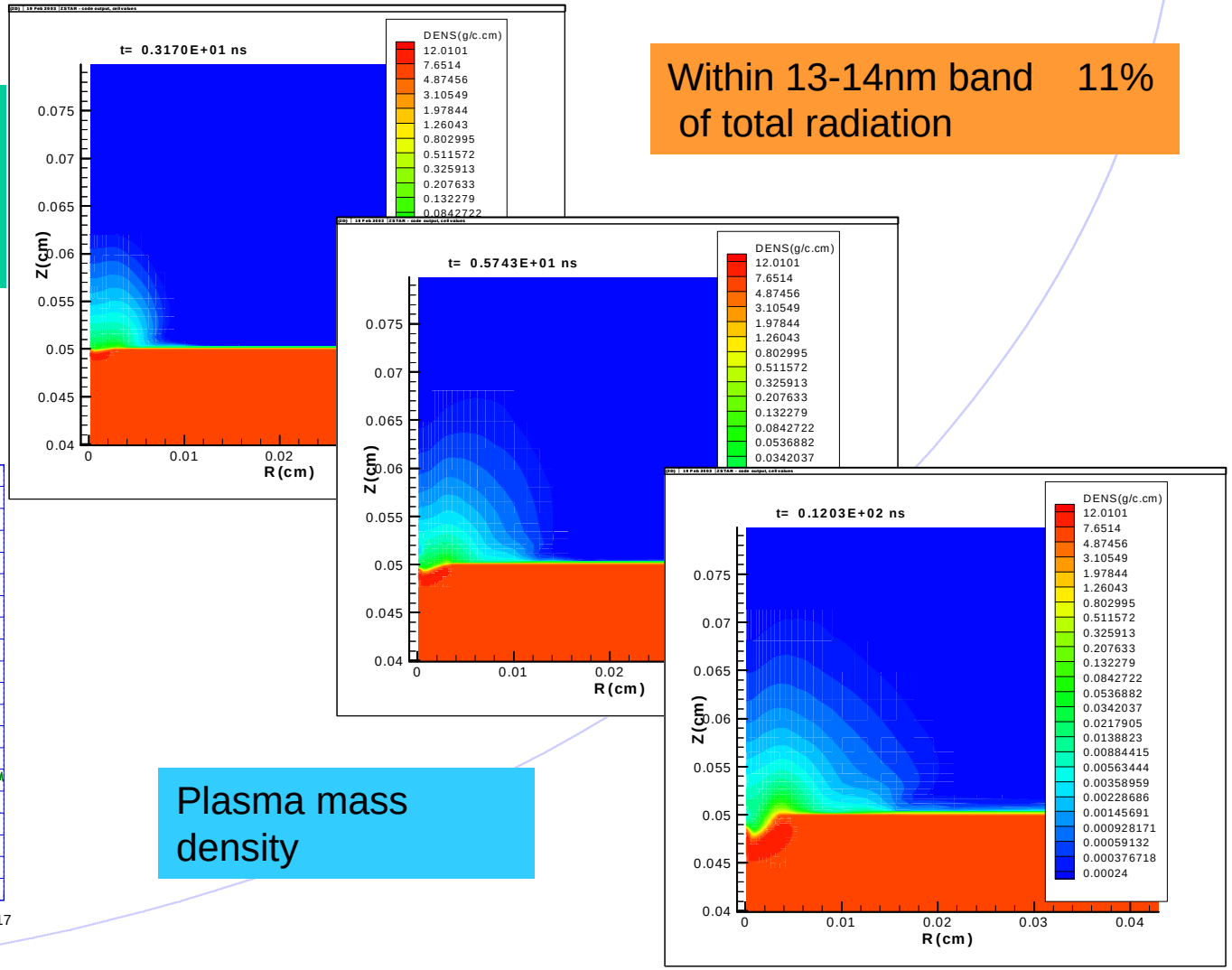


Sn

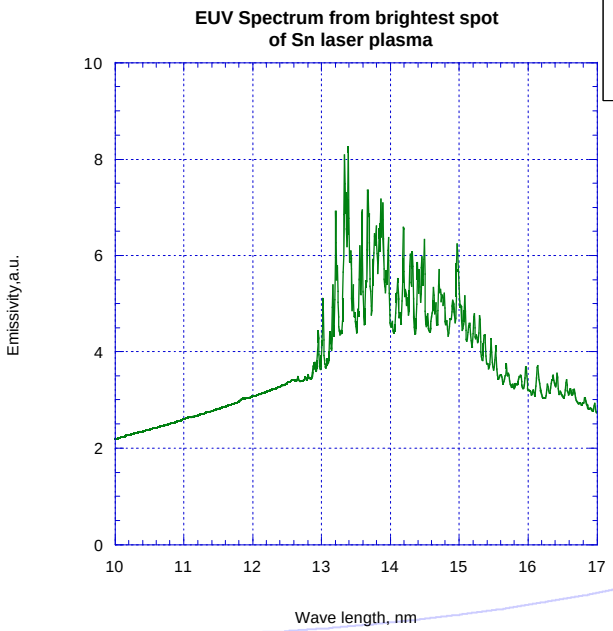
LPP Dynamics
with tin target

EUV emission source localized at 5.7ns with
ρ= 0.1 - 0.2 g/cm^3
T_e= 40 - 50eV

Within 13-14nm band of total radiation 11%



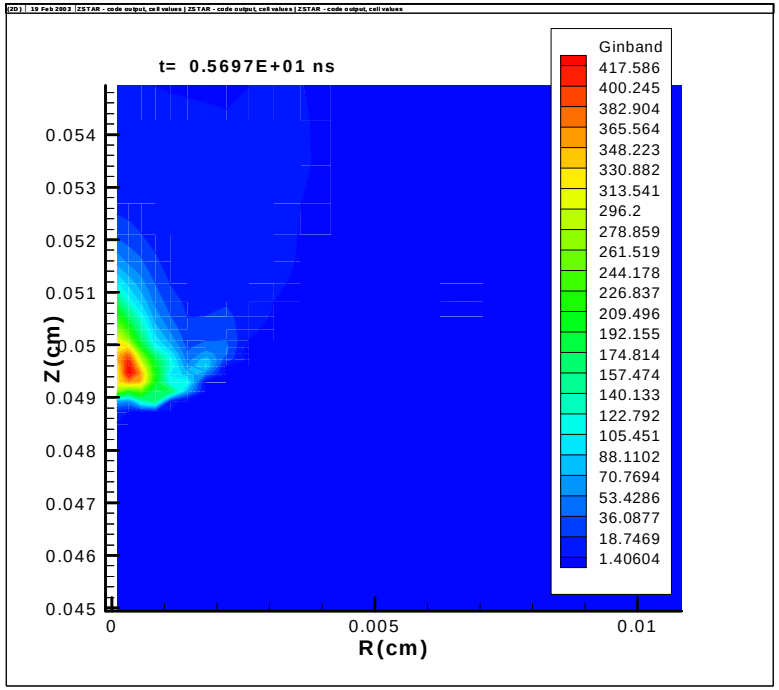
Plasma mass density



Xe

Calculated LPP Emission

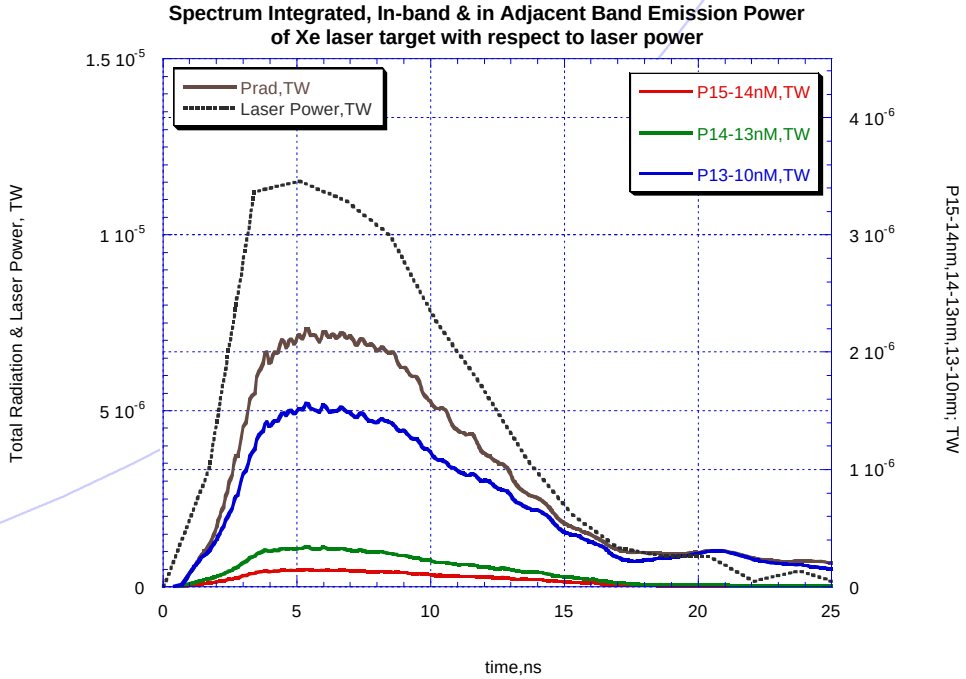
with xenon cryogenic target



13-14nm EUV emission power density at peak 5.7ns

Within 13-14nm band 5%
of total radiation

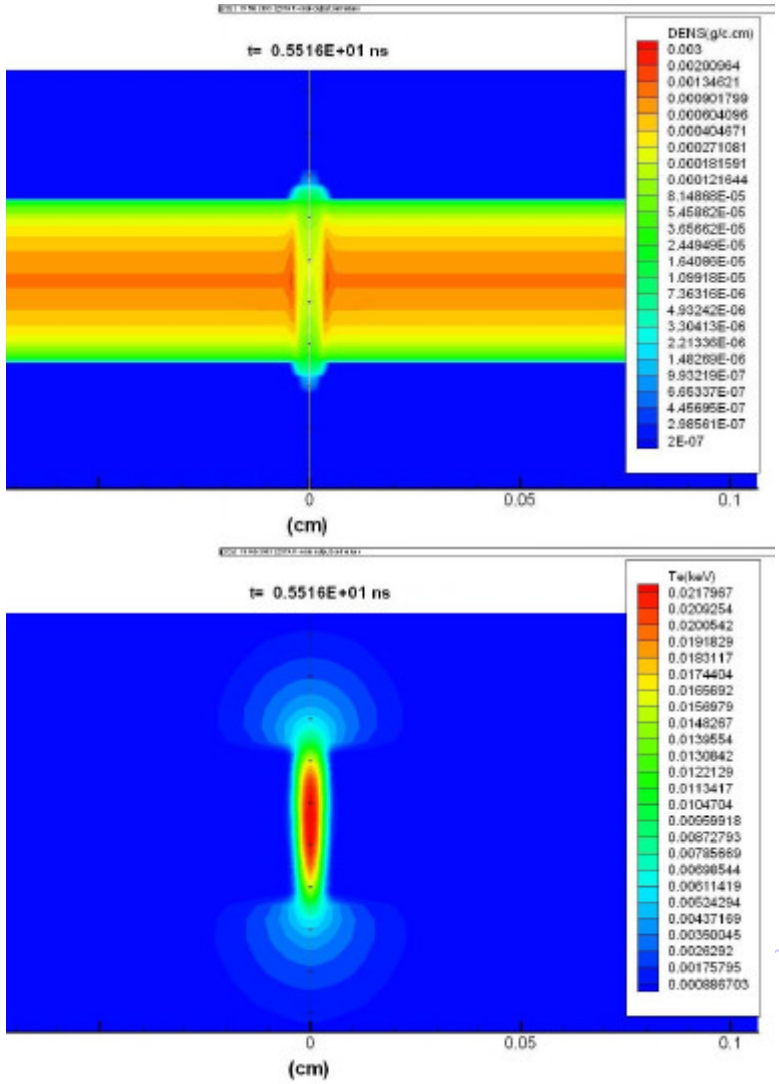
Higher emission in adjacent bands



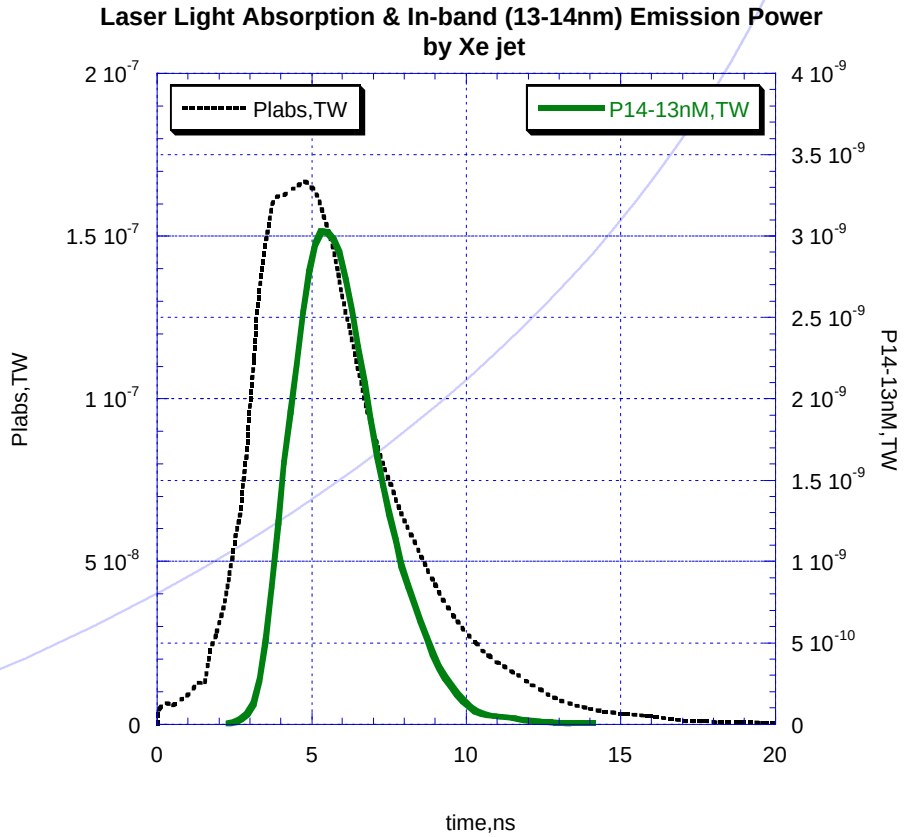
Xe

LPP Simulation

of xenon supersonic jet



Low laser energy absorption



Summary

2D RMHD code Z*

- realistic cylindrical geometry
- physics of solid materials and complex ion compound plasmas
- plasma dynamics, plasma – solid substance interaction
- multi-group radiation transport, LTE & non LTE
- detailed spectra in Xe and Sn

EUV source plasma simulations

- examine various discharge and laser produced plasma sources
- optimize geometry and plasma conditions for EUV radiation yield
- study time evolution and dimensions of EUV radiation emitter
- evaluate parametric dependence of DPF radiation
- 3D plasma compression in gradient CD
- evaluate Sn vs Xe as EUV radiator in LPP sources

- **emission efficiency complex in discharge and laser produced plasma**
- **higher radiation efficiency from Sn plasma within 13-14 nm with lower EUV out of band radiation compared with Xe**
- **low overall efficiency in Xe gas jet target in LPP**

ER2S, Inc.

Environment Remediation Solutions and Systems

CODE Z*

2-D RADIATION MAGNETO-HYDRO-DYNAMIC SIMULATIONS

Application of Code Z* to specific EUV radiation sources are available from *ER2S, Inc*. in association with *EPPRA SAS*

US Contact: Kware@ER2S.com

Acknowledgement

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