Hydrodynamics Simulation of Interpenetrating

Laser Generated Plasmas Plumes

Liska R.[1], Renner O.[2], Šmíd M.[1,2], Larroche O.[3]

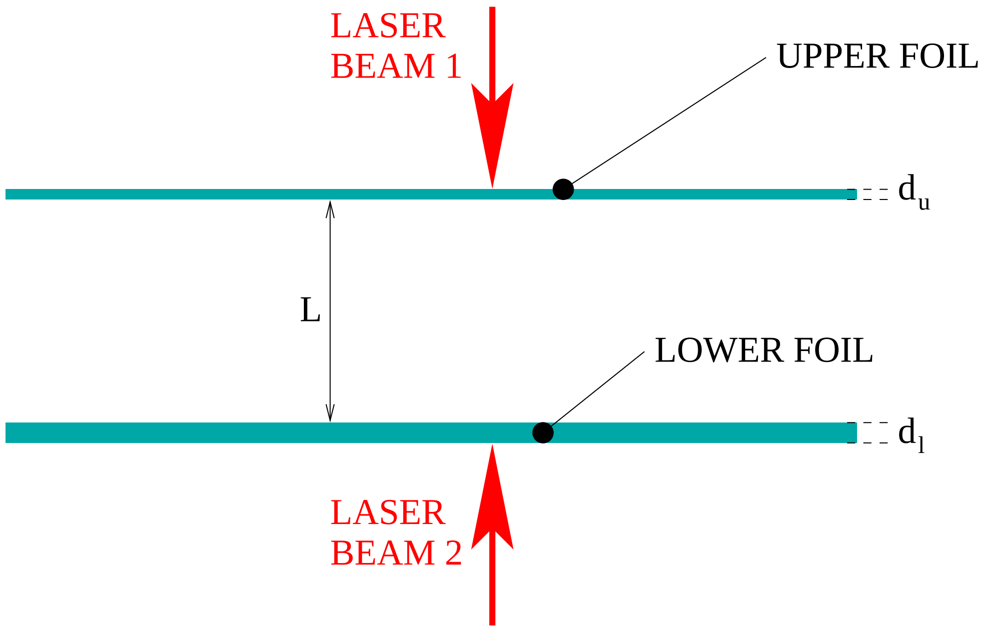
[1]Czech Technical University in Prague
Faculty of Nuclear Sciences and Physical Engineering
liska@siduri.fjfi.cvut.cz
[2]Institute of Physics, Academy of Sciences of the Czech Republic, Prague
[3]CEA DIF, Bruyères le Châtel, France

Overview

- plasma wall interaction (PWI) studies by two foil targets at PALS
- single fluid 2D ALE code PALE (Prague ALE) for laser generated plasma simulations
- single fluid model does not allow meeting plumes to interpenetrate
- multifluid hydrodynamical 1.5 D code MULTIF from O. Larroche
- hydrodynamical results postprocessing by radiative postprocessor CRETIN using atomic data from HULLAC (M. Šmíd)
- Al/Mg two foil target with 2 lasers – Al/Mg plasma plumes interact between the foils
- Al/C two foil target with oblique laser – Al plasma plume heats solid C foil

Two Foil Target

- upper Al and lower Mg foil
- foils thickness $d_u = 0.8\mu m, d_l = 2\mu m$
- foils distance $L = 600\mu m$
- stronger laser beam with energy $115\,\mathrm{J}$, 3-rd harmonics, pulse length $300\,\mathrm{ps}$, focus $r_f = 40\,\mu\mathrm{m}$, angular beam divergence 15°, focused on the upper foil



- the second, weaker laser (also on the third harmonics) with energy 6 J, FWHM 300 ps and focal spot radius 25 μm, is focused from below on the Mg foil

2D Hydrodynamical PALE Code

- **hydrodynamical model in Lagrangian coordinates**

$$\frac{\mathrm{d}\,\vec{x}}{\mathrm{d}\,t} = \vec{v}, \qquad \rho\frac{\mathrm{d}\,\vec{v}}{\mathrm{d}\,t} = -\nabla p,$$

$$\frac{1}{\rho}\frac{\mathrm{d}\,\rho}{\mathrm{d}\,t} = -\nabla\cdot\vec{v}, \qquad \rho\frac{\mathrm{d}\,\varepsilon}{\mathrm{d}\,t} = -p\,\nabla\cdot\vec{v} + \nabla\cdot(\kappa\nabla T) - \nabla\cdot\vec{I},$$

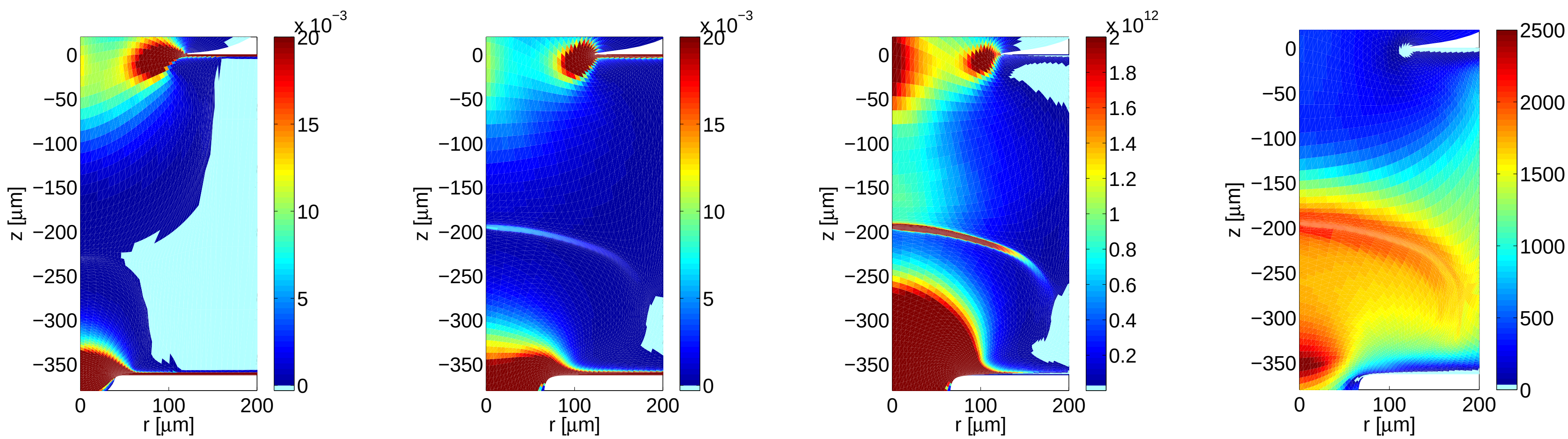
- **Equation of state: Ideal gas or Quotidian EOS (QEOS)**
- **Laser absorption on the critical surface or by ray tracing.**
- **Arbitrary Lagrangian Eulerian (ALE) method: 1. Lagrangian computation, 2. mesh smooting, 3. remapping**
- **ALE avoids mesh degeneration and tangling**

Single Fluid Results by PALE

- **single fluid model has the same velocity for both materials and does not allow them to interpenetrate**

- **impacting plasma plumes; ions decelarated immediatelly; artificially high pressure and temperature region at material interface**

- **sample results for another two foil target**



ρ **at 0 ps** ρ **at +100 ps** p **at +100 ps** $T[eV]$ **at +100 ps**

1.5 D Multi-fluid Hydrodynamical Code MULTIF

- **two (or more) ion specii are allowed to interpenetrate, each fluid has its own set of hydrodynamical quantities (density n_i, velocity u_i, thermal energy $k_B T_i$ for ions of type i)**

- **charge quasi-neutrality is ensured by a background electron fluid with density $n_e = \sum_i n_i Z_i$ and its own temperature T_e**

- **mass, momentum and energy conservation equations for each fluid**

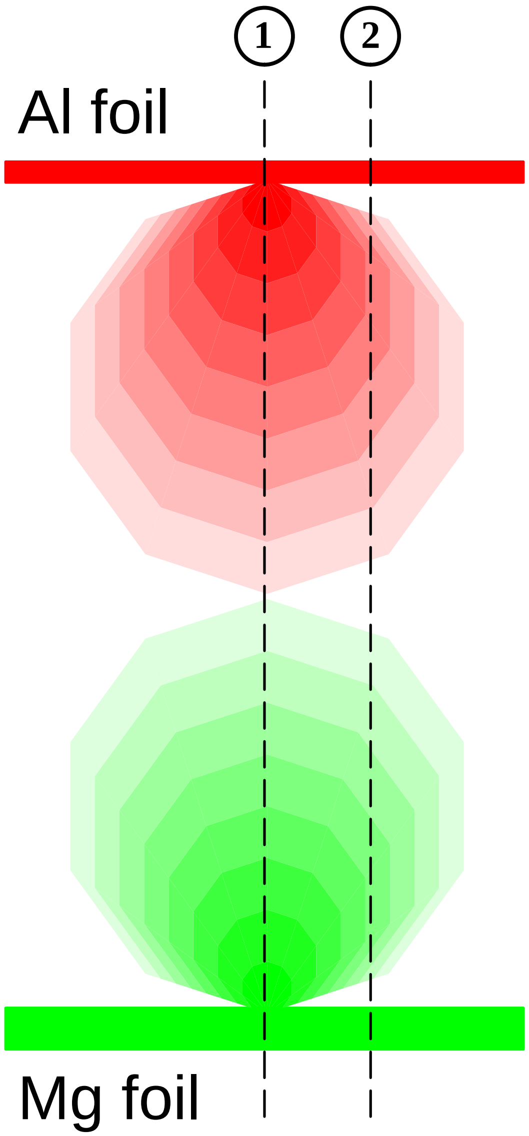
- **collisional drag (due to Coulomb collisions) as source terms in momentum and energy equations exchanges momentum and energy between fluids**

- **the efficiency of Coulomb collisions greatly vary, and so does the collisional drag which tends to decrease the relative velocities**

- **self-similar transverse expansion – "1.5D"**

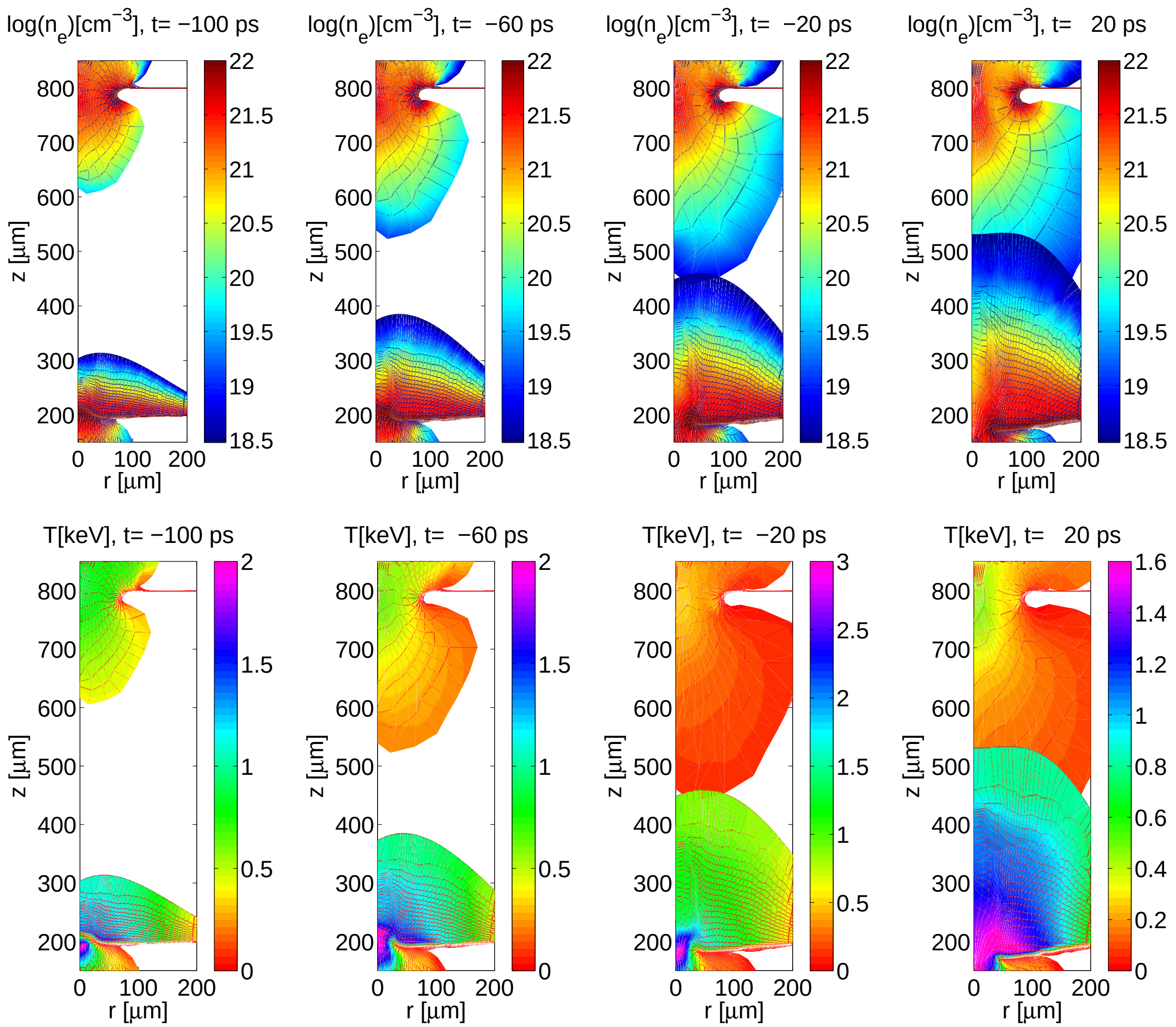
Coupling the Codes

- initial development of Al and Mg plasma plumes simulated by 2D PALE code
- from 2D maps 1D profiles are extracted and combined into a two fluid description of colliding plasmas
- these 1D profiles are lineouts along either the symmetry axis of the experiment (line "1"), or straight lines at constant radius (e. g., line "2")
- pseudo-2D results obtained by several 1D MULTIF runs



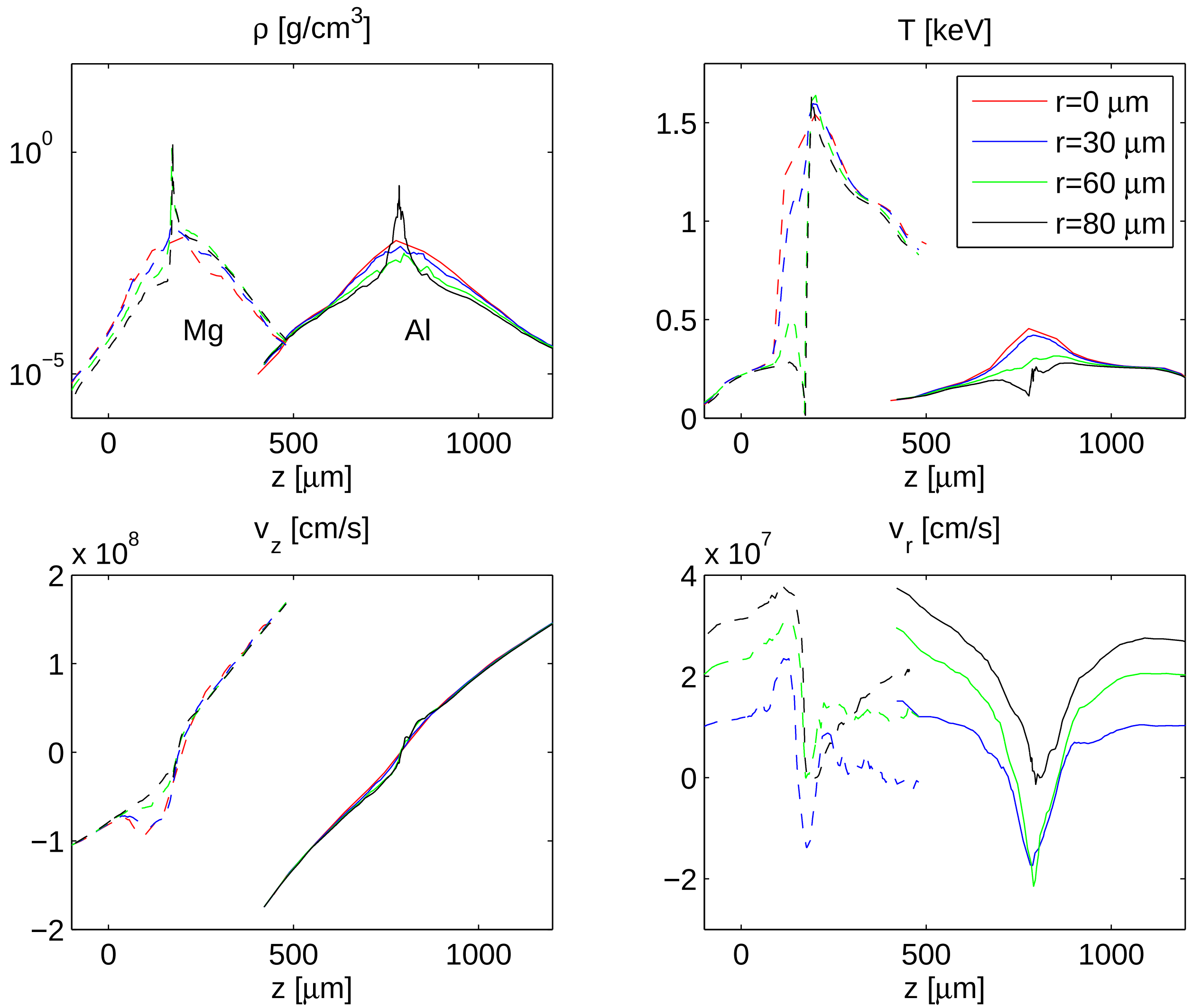
PALE 2D Results

- **separate PALE runs for each foil till time +20 ps when plumes overlap by only very low density regions**

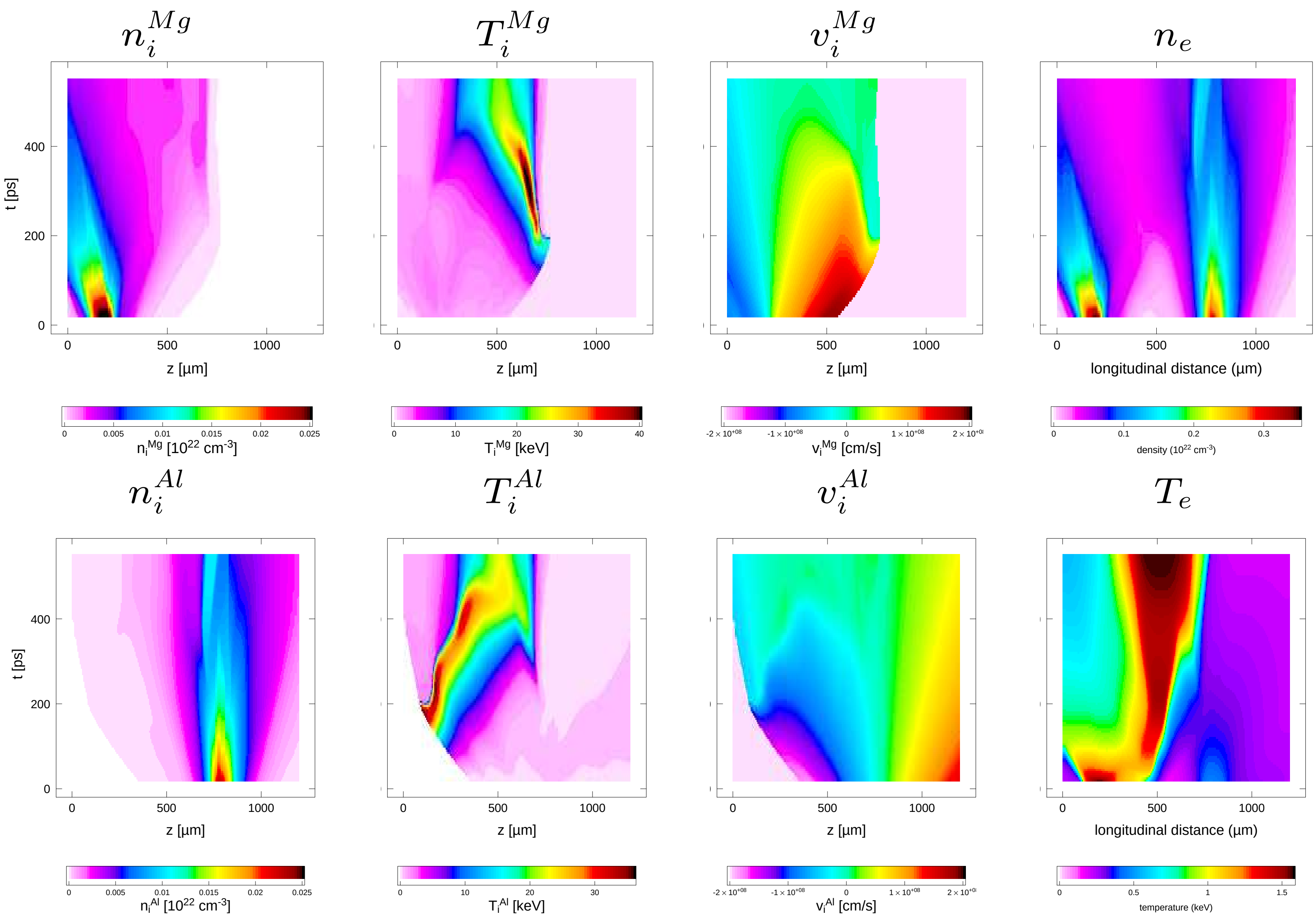


1D Cuts of PALE 2D Results

- **1D cuts of n_e, T, v_z, v_r at time $t = +20$ ps at fixed radii $r = 0, 30, 60, 80, 100, 120, 140, 160, 180, 200\mu$m serve as initial conditions for MULTIF runs**



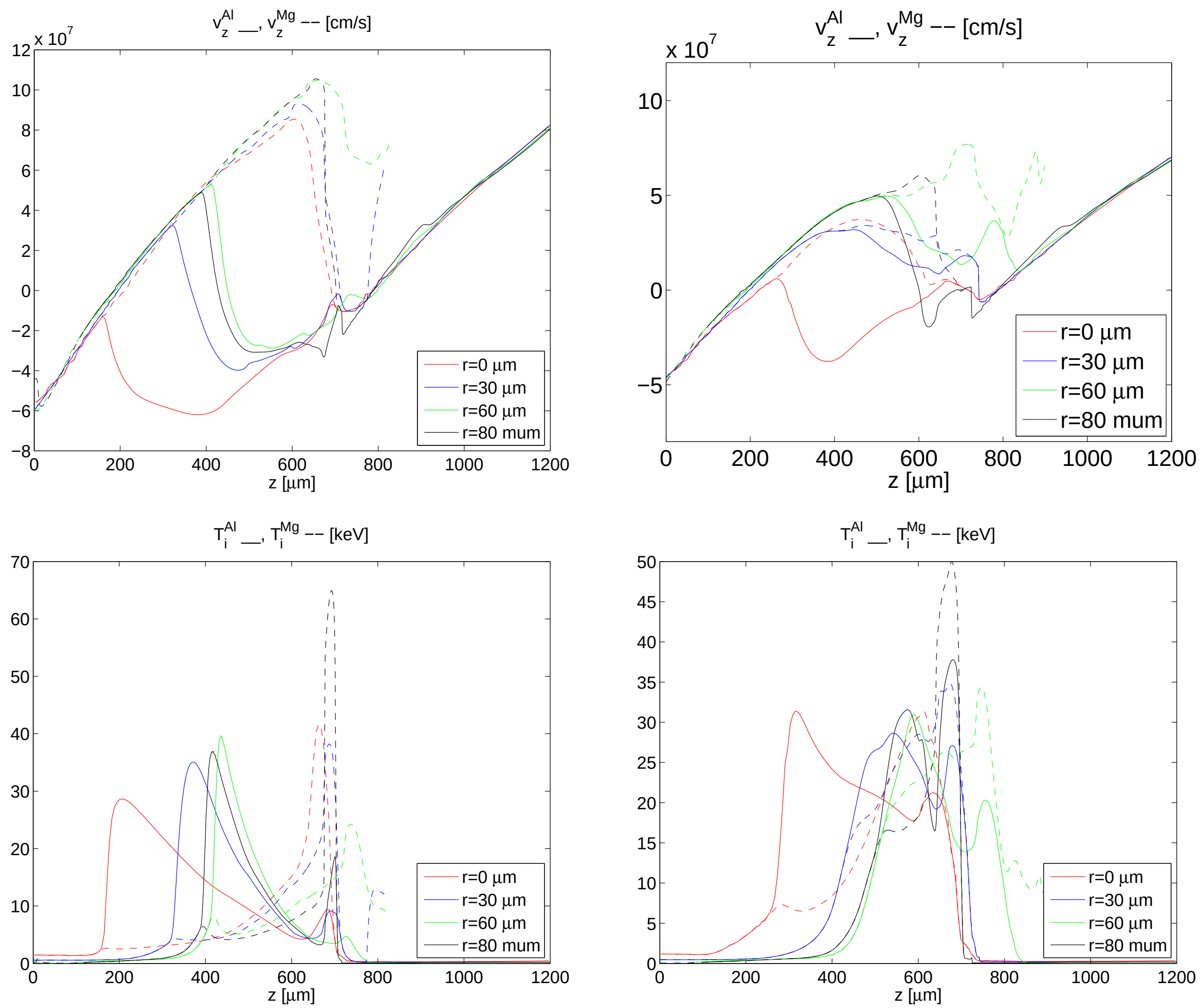
MULTIF Results of Interpenetration on the z Axis



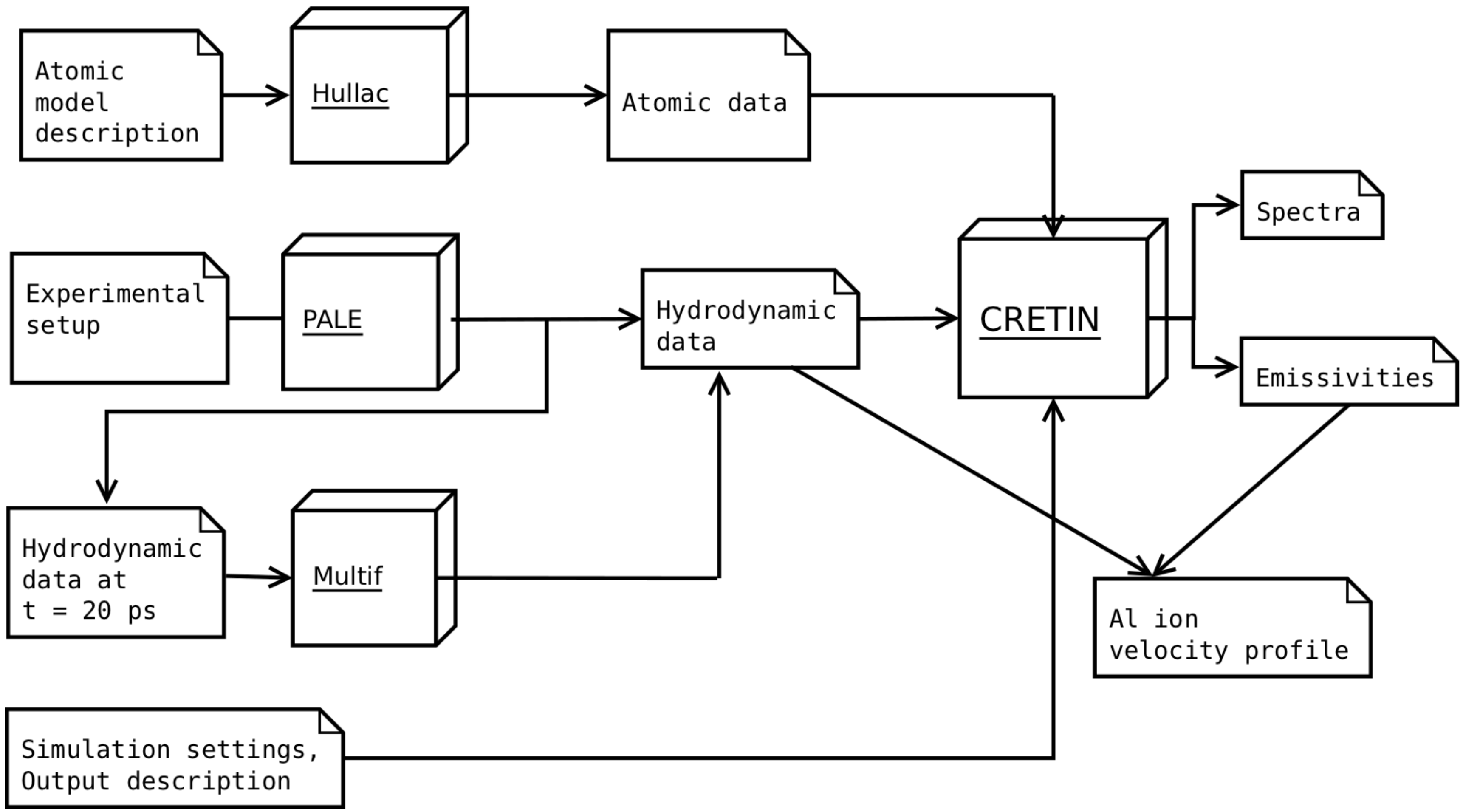
MULTIF Results

- **profiles of Al (solid lines) and Mg (dashed lines) ions velocities and temperatures**

300 ps **400 ps**



PALE - MULTIF - CRETIN - HULLAC Chain

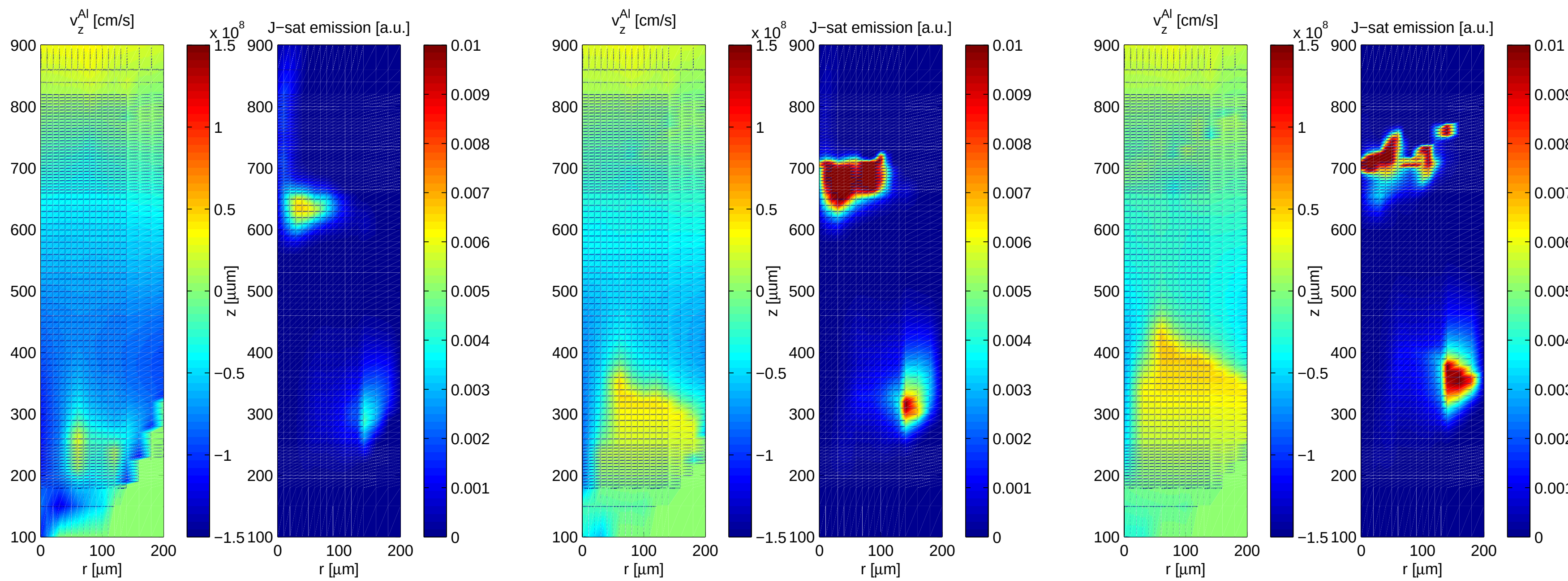


- **radiative postprocessor CRETIN computes emmisivities and syntetic spectra from results of hydrodynamical computation**

CRETIN Results

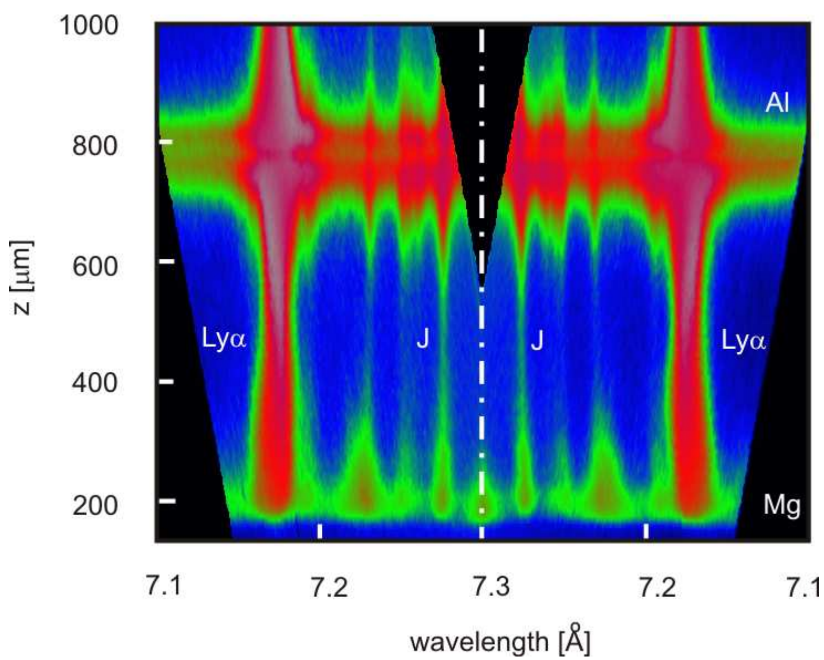
- **axial Al ions velocity and J-satelite emisivity at selected times**

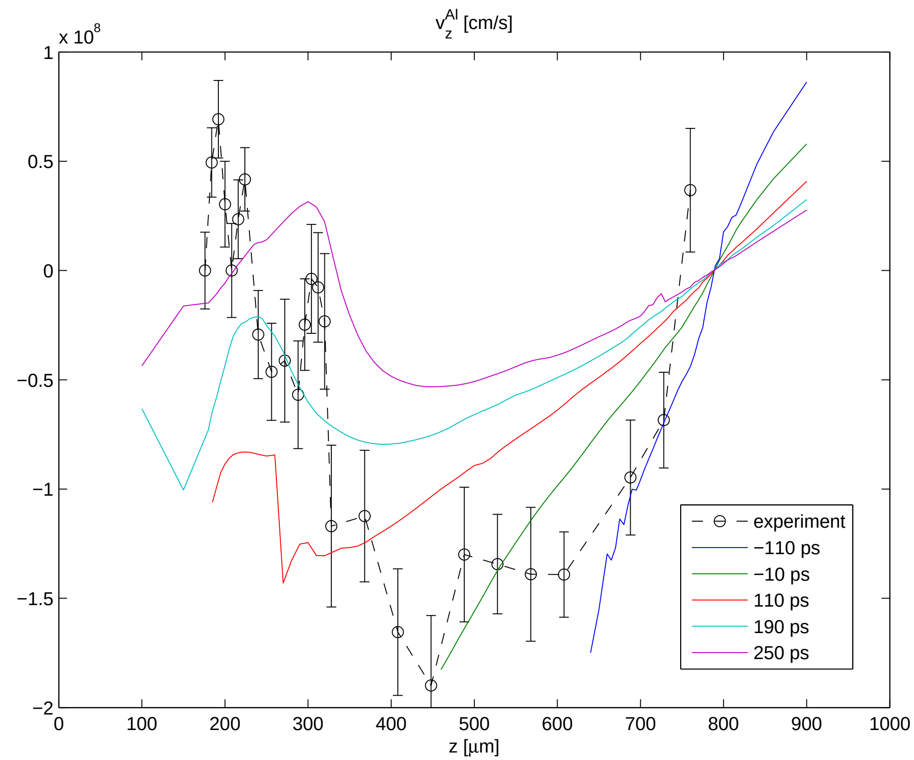
190 ps **250 ps** **310 ps**



Comparing with Experimental Results

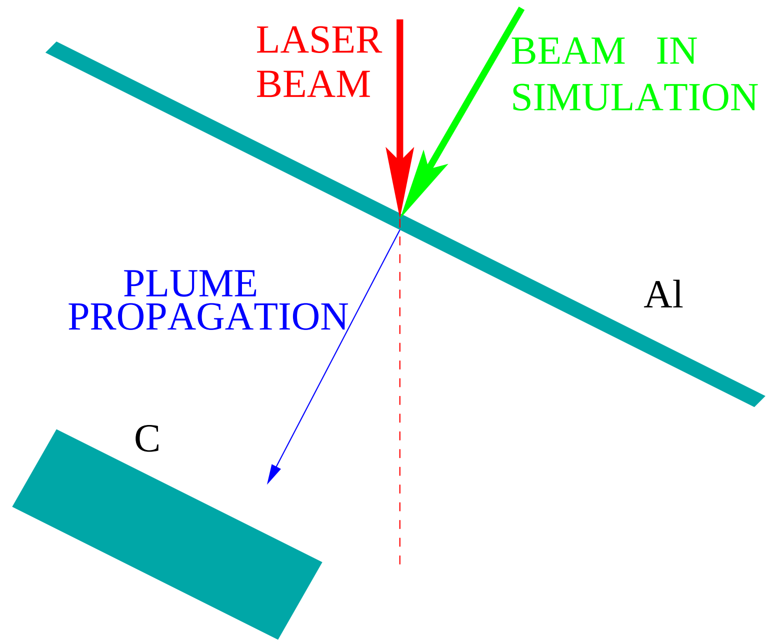
- spatially resolved emission spectra of the Al Lyα spectral group
- experimentally observed effective Al ion velocities derived from Doppler shifts of the J-satelite
- velocity profiles weighted by emisivity obtained from CRETIN





Oblique Incidence on Double Foil Target

- **upper Al and lower C foil**
- **foils thickness** $d_u = 0.8\mu m, d_l = 250\mu m$**; foils distance** $L = 600\mu m$
- **Gaussian laser beam with energy** $57\,\mathrm{J}$**, 3-rd harmonics, pulse length** $250\,\mathrm{ps}$**, focal spot radius** $r_f = 150\,\mu\mathrm{m}$
- **after burning through the Al foil laser does not hit the C foil**

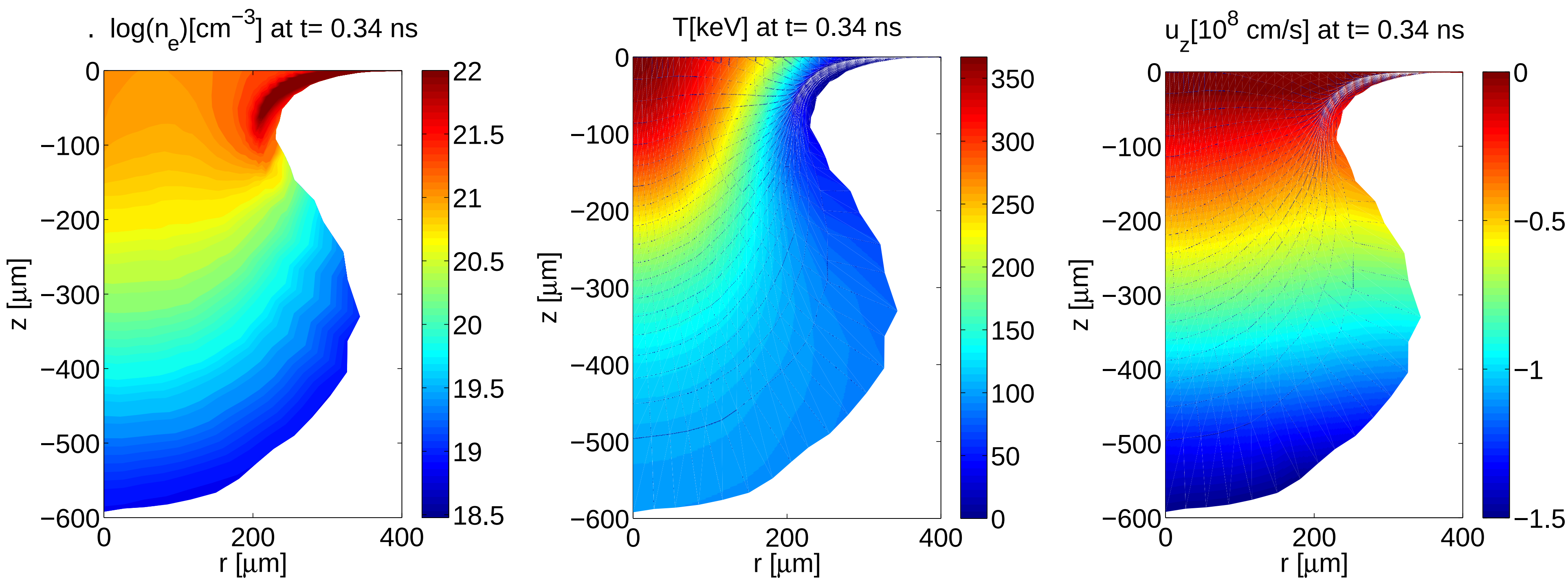


- **Al plasma plume propagates in direction orthogonal to foils**
- **oblique and orthogonal incidence produces very similar results**
- **simulation preformed in cylindrical geometry with symmetry axis being orthogonal to foils; beam is orthogonal to the foils**
- **plasma plume interaction with solid C foil; plasma wall interaction (PWI)**

PALE Simulation with Upper Foil

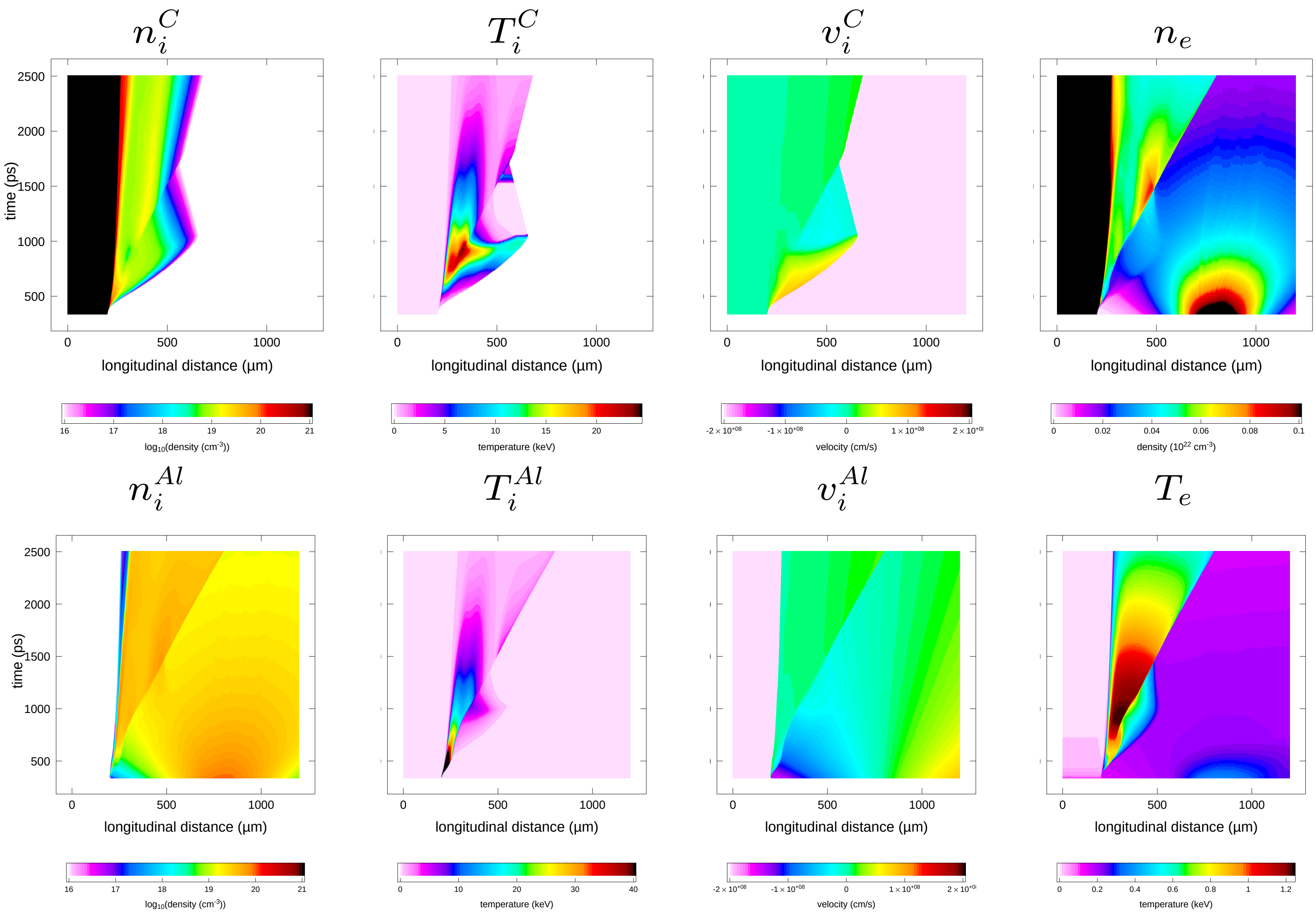
- **2D PALE results with upper Al foil at time $t = +340$ ps after laser maximum, when plasma plume hits the lower C foil**

- **1D cuts on the z axis serve as initial conditions for MULTIF code**



MULTIF Results of Wall Heating

- **Al plasma plume heats C wall, layer of Al/C mixture develops**



Conclusion

- single fluid hydrodynamical models do not allow plasmas interpenetration
- 2D single fluid ALE code PALE
- multifluid hydrodynamical 1.5 D code MULTIF
- radiative postprocessor CRETIN using atomic data from HULLAC
- plasma wall interaction studies
  - interaction of Al/Mg plasma plumes
  - interactin of Al plasma plume with solid C foil

Thank you for your attention