Laser-driven collimated plasma flows studied via ALE code

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1. INTRODUCTION

Cylindrical version of our two-dimensional Arbitrary Lagrangian Eulerian code PALE is applied for numerical studies of dense plasma jet formation from laser targets. The code is briefly described in section 2. Well-collimated plasma expansion from a massive solid target irradiated by a single laser beam with a special profile is investigated in section 3. Fluid simulations of highly efficient acceleration and collimation of high-density plasma using ablation pressure enhancement by cavity confinement are presented in section 4.

2. ARBITRARY LAGRANGIAN-EULERIAN CODE PALE

A typical Arbitrary Lagrangian-Eulerian (ALE) method consists of three steps: a Lagrangian solver, advancing the solution to the next time step; a rezoner, improving geometrical quality of the computational mesh; and a remapper, interpolating conservatively all fluid quantities from the Lagrangian to the rezoned mesh. Due to the Lagrangian solver, the computational mesh naturally follows the motion of the fluid, so it is very suitable in case of severe compressions or expansions of the material, often present in the laser-plasma interactions. On the other hand, the Eulerian part of the method (consisting of mesh rezoning and quantity remapping) prevents the simulation from failure due to the mesh degeneracy.

Our two-dimensional (2D) fluid ALE code PALE [1] incorporates a staggered Lagrangian solver [2], treating all thermodynamic quantities in the mesh cell centers, and all kinematic quantities at the mesh nodes. As a mesh rezoner, we use the classical Winslow smoothing [3], employed in warm regions only. For remapping, the swept-region based approach followed by a repair stage enforcing the local-bound preservation requirement [4] is used. The code incorporates the QEOS equation of state, the Spitzer-Harm heat conductivity model with a flux limiter, and laser absorption on the critical surface.

3. JET FORMATION IN CORONA OF PLANAR TARGETS

Simple reproducible generation of collimated outflows (jets) with propagation distance ex-

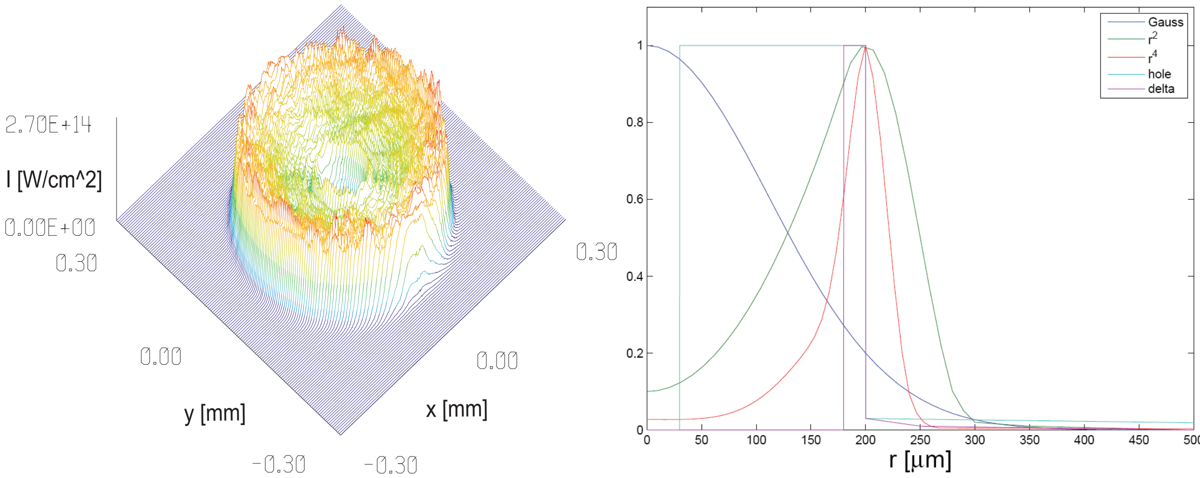

Figure 1: (Left) Calculated intensity profile of the third harmonic (3ω) laser beam at the position 800 μm ahead of the geometric focus. Perturbed active gas mixture in the iodine laser amplifiers and low-level turbulence in air are assumed. (Right) Various types of smoothed normalized intensity distributions used in fluid simulations.

ceeding 10 jet diameters is very important for laboratory studies relevant to astrophysics [5] and also for a new fast ignition concept [6]. Sharp, dense plasma jets are usually produced from special targets using sufficient laser energy of kJ order. Recently, well-collimated jets have been produced by a less energetic laser beam at planar targets at NHELIX [7] and PALS lasers [8]. Both laser systems were equipped with focusing lens with a central aperture.

Here, we investigate in detail the impact of intensity profile in the PALS laser spot on jet formation. In order to explore details of the PALS interaction beam profile, we have modelled the PALS beam propagation in the laser system and in the interaction chamber optics. A physical-optic simulation with a complex amplitude representation of the beam wavefront and intensity was selected for our calculation of the interaction beam profile. We have used General Laser Analysis and Design (GLAD) ver. 5.3 by Applied Optics Research [9] for the simulation. Plasma jets are produced when the target surface is placed slightly out of the geometrical focus and thus the calculated intensity profile of the laser spot 800 μm ahead of the laser focus is presented in Fig.1 (left panel). Several types of laser intensity distribution, plotted in the right panel of Fig.1, have been used in numerical simulations.

An example of jet formation is demonstrated in Fig.2. Electron density distributions are plotted for 4 different delays after the maximum of 300 ps-long pulse of iodine laser third harmonic (λ = 439 nm). Laser beam of energy 2 J is incident normally on solid planar aluminium target; r^2 intensity profile (green curve in the right panel of Fig. 1) is assumed. Wave leading to cylindrical cumulation is apparent in the first 2 panels. Our simulations show that jet formation is rather sensitive to laser spot intensity profile. The r^2 intensity profile is the optimal profile for formation of narrow stable jets, jet is also clearly observed for the

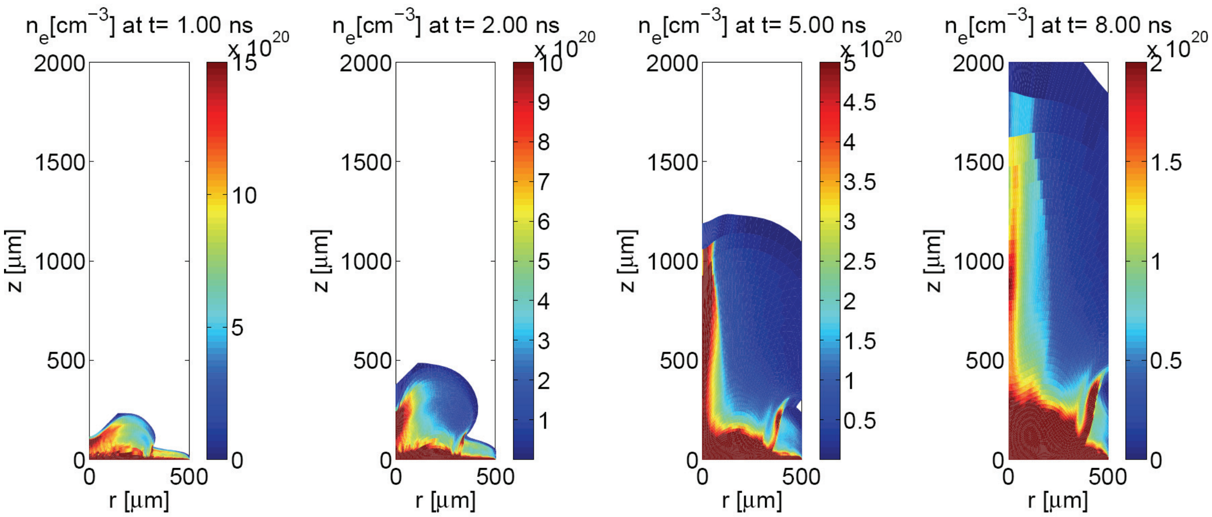

Figure 2: Formation of dense narrow jet is demonstrated on plots of electron density at various delays after laser pulse maximum. Laser of energy 2 J, wavelength 439 nm and pulse duration 300 ps is incident normally on solid thick planar Al target. Laser intensity in the beam centre is 10% of the maximum intensity; intensity grows as r^2 at small radii and reaches its maximum at radius 200 μm.

"hole" profile (cyan curve in Fig. 1 right panel), while r^4 and "delta" profiles seem not to be suitable for stable jet creation. Collimation of plasma outflow decreases with increasing laser intensity and thus contribution of other mechanisms, such as radiative cooling, is necessary for formation of highly collimated jets, observed at PALS for high-Z materials only [8].

4. LASER DRIVEN TARGET ACCELERATION IN CHANNEL

Preliminary results are presented of numerical simulations of experiments at PALS laser aimed to the efficiency enhancement of the ablative acceleration by a cavity. Three experimental layouts (Fig. 3) were used in experiments [10, 11]: (**L-T**) direct laser interaction with solid targets, (**AA**) foil ablative acceleration and (**LICPA**) laser induced cavity pressure acceleration. Shape and volume of craters were measured in all above experimental layouts. The rear side of the cylindrical channel was open in some of the targets and thus, the velocity and the shape of the accelerated target material were measured via 3-frames interferometry.

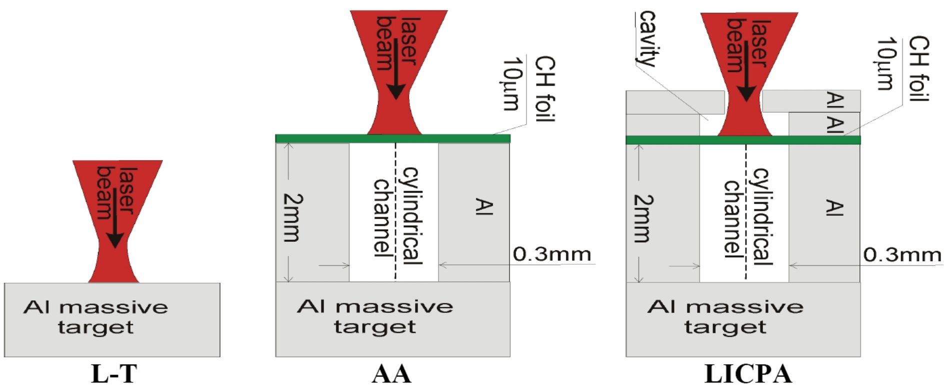

Figure 3: Studied experimental layouts [10, 11]. Cylindrical symmetry along laser axis was assumed.

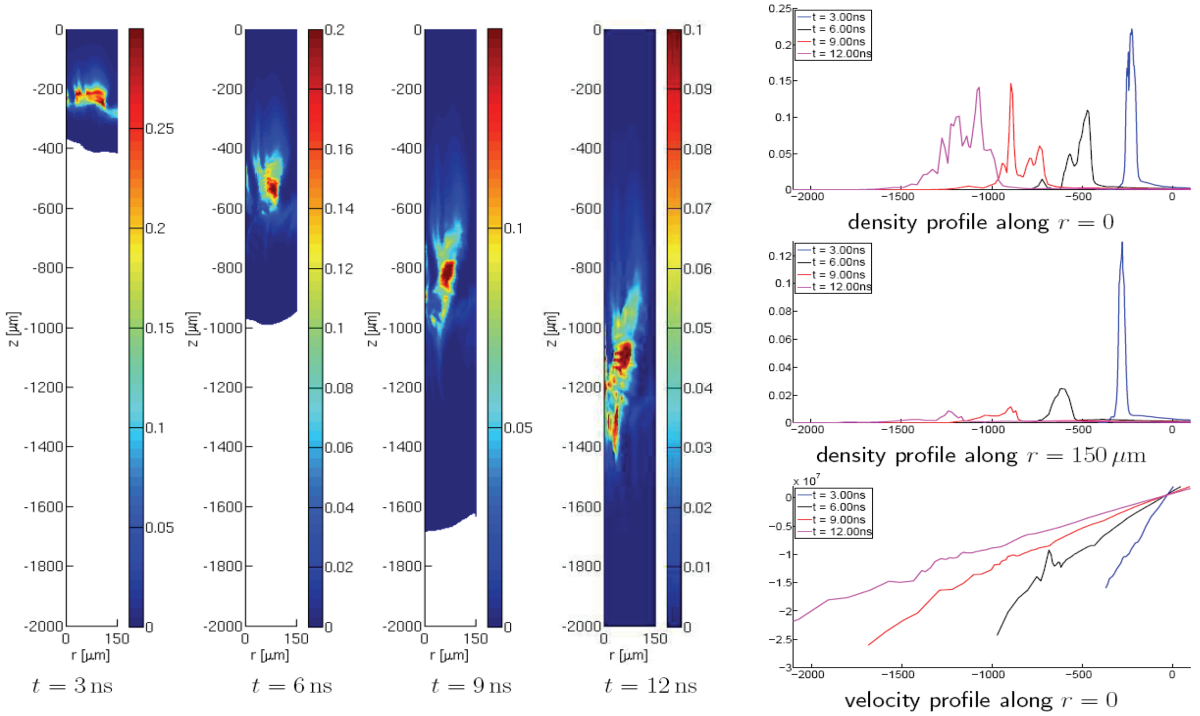

Figure 4: Interaction of iodine laser beam of energy 130 J and pulse duration 0.3 ns with 10 μm-thick CH foil in 2 mm-long channel of radius 150 μm covered by 150 μm deep cavity (LICPA). Mass density in g/cm^3 at various delays after laser pulse maximum (left), density and velocity in the channel centre and on the wall (right).

Fluid simulation of the foil acceleration in the LICPA scheme is presented in Fig. 4. 300 ps FWHM laser pulse of energy 130 J and wavelength 1.31 μm was assumed to be focused into 150 μm-deep cavity with entrance hole closing immediately after laser-foil interaction. The foil acceleration is enhanced by the plasma pressure in the cavity. The calculated plasma velocities 4.5×10^7 m/s for LICPA and 2×10^7 m/s for AA scheme at the open channel outlet compare well with the measured experimental values.

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