Laboratory Astrophysics using High Energy Lasers: need for 2D simulation

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Abstract. A certain number of experiments have been performed and planned for the future aiming to reproduce in a laboratory common astrophysical situations [1]. Among those, astrophysical jets have been the subject of elaborate studies in both theory [2] and observations [3]. Nevertheless, they still raise problems such as the “jet collimation”.

Two different approaches have been recently proposed and investigated: Vfoil [4] and Foam filled cones [5]. We present here the numerical approach to simulate such phenomena to better understand the mechanism underneath the jet formation. Numerical simulations can serve also as useful tool to guide decisions regarding the future experiments.

1. Introduction

The code used for these simulation is DUED which is a Lagrangian 2D multigroup radiative-hydrodynamic code developed in Rome [6]. In the present work few modifications had been added: an anti-drift method has been used to avoid pathologies and ad hoc modeling for symmetry have been induced to suit common experimental targets and configurations [7]. SESAME tables [8] for the equation of state and multigroup opacity from SNOP code (hydrogenoid model [9]) have been used. We used typical parameters for LULI laser $I \sim 10^{14}$W/cm² and $\Delta t \sim 1$ns and focal spot of 500 (with Phase Zone Plates [10]) or 300 microns (with Random Phase Plate [11]).

2. Interaction between two expanding plasmas in vacuum (Vfoil)

The target is made of two Aluminium foil with an angle between the two of 90° (see picture 1 and [4]) and laser is focused on the external part of each foil using RPP ($I \sim 10^{14}$W/cm²).

A shock wave is generated by laser ablation in each Al foil resulting in expanding plasma on the rear side of the target. The two plasmas expand away from the rear side of the foils and then collide, resulting in stagnation, and a bulk axial flow of heated material.
Expanding plasma
Jet
Collision
Angle
z
y
x

**Figure 1.** Diagram of the experiment. Two laser beams are focalized on two thin Al foils (5 or 3 µm). The rear side expanding plasma collide on the central axe giving rise to a stagnation region which generates a jet propagating into vacuum.

2.1. **2D simulation**

This configuration has a symmetry plane that doesn’t reduce the 3D evolution of the plasma to a 2D problem. We decided to reduce the problem to a 2D case using a Cartesian coordinate system and symmetry along the plane between the two foils. Once a lagrangian cell reaches the symmetry plane, it is stopped. This means that there will be no penetration of one flow into the other. This is a direct consequence of the symmetry, in fact once the cell reaches the $y=0$ plane, on the other side it will find the same pressure, thus stopping the hydrodynamic motion in the $y$ direction.

![Diagram](image)

**Figure 2.** Diagram of the experiment. Two laser beams are focalised on two thin Al foils (5 or 3 µm). The rear side expanding plasma collide on the central axe giving rise to a stagnation region which generates a jet propagating into vacuum (dimensions are in microns and the colour bar represents the density in gr/cm$^3$).

This jet mechanism generation is easily found on the simulation. In figure 2 we show four snapshot at different delays. We observe the heating and ablation of the thin Al foil (0.5 ns), the rear side expansion of the plasma (5 ns) at $v \sim 90 \text{km/s}$. A stagnation region (conditions: $v < 40 \text{km/s}$, $P = 1 \text{Mbar}$, $T_e = 25 \text{eV}$ and $Z^* = 4.5$) is present at when the two plasmas collide on the central axis ($7.5 \text{ns}$) generating a strong jet in the axial direction; in the snapshot at $12.5 \text{ns}$, we can see the formed jet. The velocity of the jet is $v \sim 120 \text{km/s}$ on the tip, the temperature is $T_e 15 \text{eV}$ and its collimation is granted by the external plasma (“Collector” in the picture) that guides the jet flow along the symmetry plane. This is one of the key points of the experiment, in fact this surrounding cold ($T_e \sim 1 \text{eV}$) and quite slow ($v \sim 10-40 \text{km/s}$) plasma act as a “wall” and do not let the jet unload in the transversal direction.

3. **Foam filled cone**

A different configuration is hereby used to generate a fast jet using High Energy Lasers: foam filled cone (figure 3). The target is composed by a double layer pusher made of plastic (20µm)
and Ti (3\(\mu\)m) on which the laser is focalized. A strong shock is generated by laser ablation into a cone filled with foam (\(\rho_0 = 0.05 - 0.20\)g/cm\(^3\)).

**Figure 3.** Diagram of the experiment. A laser is focalized onto a pusher (plastic+Al) that drives a strong shock into the cone filled with foam. At the exit of the cone tip a jet is observed.

We present here 2 different simulations corresponding to 2 different experimental cases. The first one (upper part of figure 4) uses a big angle cone (38\(^\circ\)) with a foam initial density of 0.05g/cm\(^3\) and is irradiated by a laser of 10\(^{14}\)W/cm\(^3\) with a flat spot generated with the use of the Phase Zone Plate [10]. The second (lower part of figure 4), uses a small angle cone (22\(^\circ\)) with a foam initial density of 0.20g/cm\(^3\) and is irradiated by a laser of 1 \(\times\) 10\(^{14}\)W/cm\(^3\) with a gaussian spot generated with the use of the Random Phase Plate [11].

### 3.1. 2D simulation

**Figure 4.** Corresponding 2D simulation of the experiment. The laser beams are focalized on the pusher that till drive a strong shock in the foam filled cone. Upper strip: simulation at 10\(^{14}\)W/cm\(^2\), \(\rho_0 = 0.05\)g/cm\(^3\) and 38\(^\circ\)cone angle. Lower strip: simulation at 10\(^{14}\)W/cm\(^2\), \(\rho_0 = 0.20\)g/cm\(^3\) and 22\(^\circ\)cone angle (dimensions are in microns and the colour bar represents the density in gr/cm\(^3\)).

To simulate the cone inner wall, we decided not to let the cell along the wall expand outside and just let them slide along the cone inner wall (*i.e.* an infinite mass wall).

The mechanism of the jet generation is shown in figure 4 in which we present for each simulation, a strip of 4 snapshots of the target evolution. As we can observe from the second picture of the two simulations, a planar shock is generated for the first case (and we can see the
shock reflected from the inner cone wall, travels with the central shock) and a more “bumpy” shock for the second (the reflected shock is behind the central shock). In both cases, the transversal shock converges at the centre (towards \( r=0 \) axe), but the evolution is a bit different for the two: for the first one, the two shocks collide at the centre \( \text{at the same time} \) generating a strong compression of the foam (that will drive the jet expansion into the vacuum), while in the second case, the transverse shock concentrates the matter \( \text{after} \) the shock breakout. This means that the pinching will generate a shock that will propagate behind the shock an thus the jet will have a lower gain.

4. Conclusions

We have presented in this paper two different approach to generate a jet in laboratory using High Energy Lasers and we studied the mechanisms of the jet generation, using a versatile and robust 2D code (DUED) with few modifications.

We pointed out that it is important to study the behaviour of the stagnation region in both case to optimize future experiments.

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