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MODELLING AND LABORATORY EXPERIMENTS OF ASTROPHYSICAL RADIATIVE SHOCKS

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Abstract. Radiative shocks might be encountered in various astrophysical systems. Therefore, there is a growing interest in producing radiative shocks in laboratory experiments as well as in modelling them with numerical simulations in order to calibrate and analyze the experiments.

We present both simulations and an experiment of radiative shocks in xenon cell at low pressure. We first present the results obtained by the radiative shock experiment held at the PALS laser (Prague) in November 2005, where for the first time, the propagation of the shock was recorded over a very long period (40 ns). We then present simulations of this experiment performed using the radiation-hydrodynamics code HERACLES. We have shown, using these simulations, that multi-dimensional lateral radiative losses are determinant for the propagation of the radiative precursor. Assuming a wall transmision of 60% allows to reproduce very well the propagation of the radiative precursor and also gives a good agreement on the transmission coefficient upstream and inside the precursor.

1 Introduction

A radiative shock is a shock where the hydrodynamical structure of the flow is affected by radiation. The radiation emitted by the shocked gas is absorbed by the cold unshocked gas, and it changes the hydrodynamical structure of the flow with the creation of a radiative precursor upstream of the shock. These shocks occur in various domains such as pulsations of evolved stars, accretion flows during stars birth, supernovæ explosions and high energy laser experiments.

Discrepancies between experiments (Vinci et al. 2005, Leibrandt et al. 2005) and 1D numerical simulations seem to indicate that multidimensional aspects, in particular lateral radiative losses, have great consequences upon the shock propagation (Bouquet et al. 2004, Leygnac 2004). To study these losses we conducted an experiment on the PALS laser (Jungwirth et al. 2001) with a very long cell which allowed a great increase in the recording time compared to previous experiments. We first briefly present the experimental setup and results which are then analyzed using the HERACLES code (González & Audit 2005; González et al. 2006a).

2 Experimental setup

In this experiment, the cell in which the radiative shock propagates is a glass rectangle of 4 mm length and 700 μm square section. It is filled with xenon at 0.2 bar. The piston which is ablated by the laser impulsion and creates the radiative shock by rocket effect, is made of two layers: a 10 μm plastic one and a 0.5 μm gold one. The 3ω (i.e. 438 nm) laser impulsion lasts 0.35 ns and is focalized in order to have a uniform focal spot of approximately 650 μm and a resulting intensity of 1 - 1.5 10^{14} W/cm^2. The experiment is then analyzed with a transversal probe green laser. After crossing laterally the cell, this beam crosses a Fresnel biprism in order

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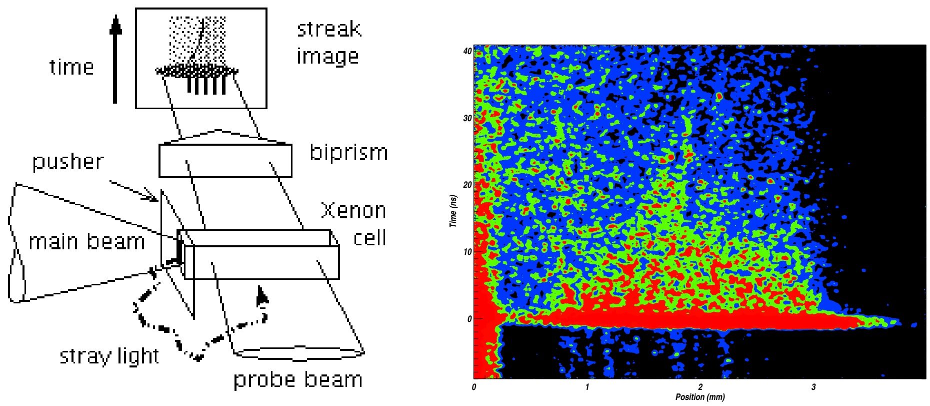

Fig. 1. Left: Schematic experimental setup. Right: false color image of the streak camera recording. The shock propagates from the left to the right. The horizontal bright spot occurs during the laser pulse, 10 ns after the beginning of the record. The initial position of the piston is on the left.

to make an interferogram of the electron density, which is recorded by a streak camera (for further details on experimental setup and results, see González et al. 2006b).

Figure 1 illustrates this experimental setup and displays the streak camera recording obtained. The main features of the recording is a parabolic discontinuity separating two regions of different intensity.

3 Modelling

We use two codes to model the experiment. First, the 1D MULTI Lagrangian code (Ramis et al. 1988) is used to determine the piston velocity. This code can deal with multi-material problems and is hence appropriate to simulate the interaction between the laser and the piston. The simulations performed show that the shock velocity is almost constant and equal to 60 km/s. But such a code is not appropriate to treat multi-dimensional effects.

We then use the 3D HERACLES code (González & Audit 2005; González et al. 2006a) to take them into account. We take the results of the MULTI simulation as an input for HERACLES. The xenon opacities used are those of the Planck mean given by the STA code (Bar-Shalom et al. 1989). The only free parameter in these simulations is the albedo of the cell walls. This albedo is characterized by the percentage of light which is transmitted by the wall, the other part being reflected. We then perform different simulations varying this parameter to reproduce the experiment. In order to do a parametric analysis at a reasonable computational cost, we have performed 2D axisymmetric simulations after showing on a test case that it gave the same results as a 3D square cell simulation as long as the ratio surface over volume was kept constant.

A result of 2D simulation performed by HERACLES is displayed on Figure 2. The left vertical boudary corresponds to the symmetry axis, the right one has a transmission coefficient of 60% and the shock travels from down to top. We can see on the temperature map that the shock is slightly bent due to the radiative lateral losses. They also imply that the compression factor near the cell wall is increased compared to the one on the symmetry axis. Figure 3 displays the profile of these two quantities along the symmetry axis. The density profile shows two peaks, one at the shock position and the other one at the front of the precursor. On the other hand, the temperature decreases slowly from 15 eV in the shock to about 5-10 eV in the precursor.

The left panel of Figure 4 shows the influence of the transmission coefficient parameter upon the shock and the precursor velocity. One can see that the shock speed is roughly unaffected by it whereas the precursor slowdown varies a lot. This panel shows clearly that the parabolic curve observed in the experiment cannot be the shock but the precursor. When the wall transmission is set to 60%, the radiative precursor trajectory reproduces very well the discontinuity observed in the experimental recording, as shown in the right panel of Figure 4.

Once the transmission coefficient of the wall was fixed to reproduce the position of the discontinuity, we

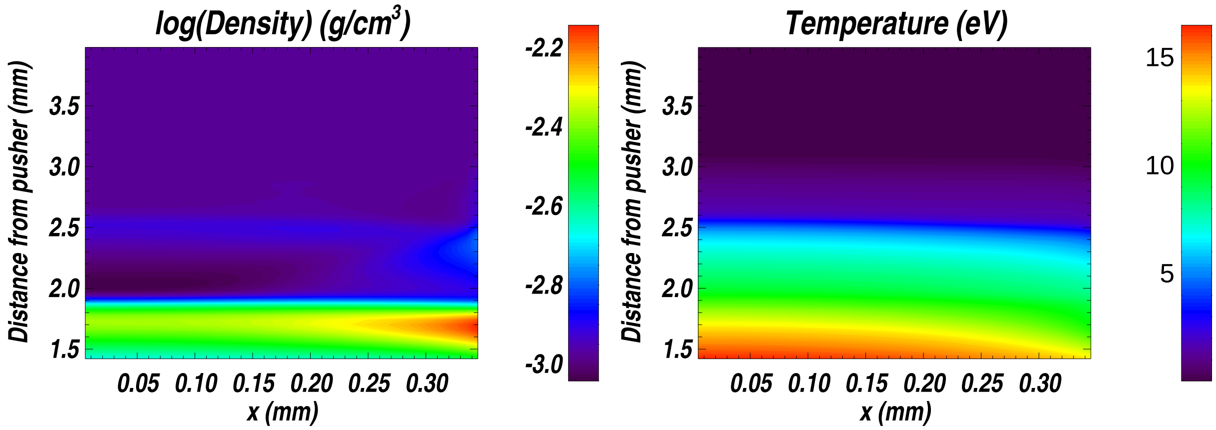

Fig. 2. Maps of density (left) and temperature (right) of a 2D axisymmetric simulation performed by HERACLES with a wall transmission of 60%.

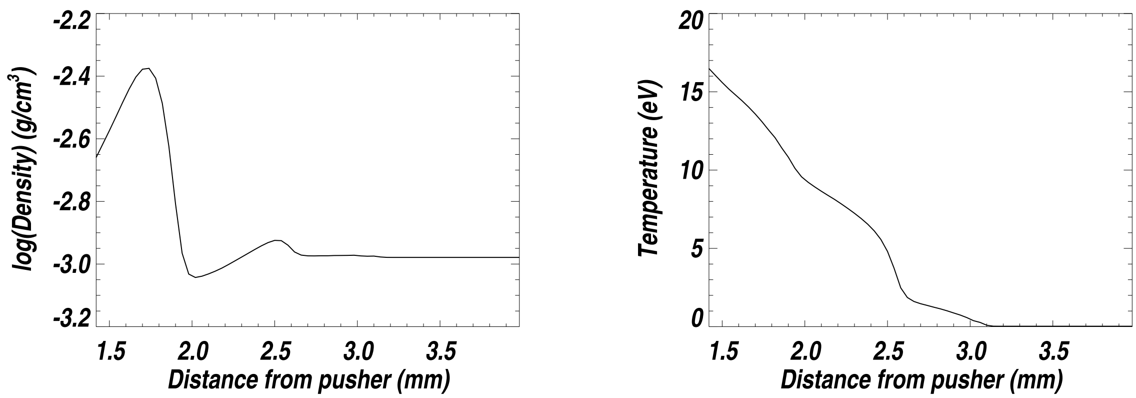

Fig. 3. Profiles of density (left) and temperature (right) along the symmetry axis of the Figure 2.

have also checked that the intensity constrast across the discontinuity could be reproduced in the simulation. To do so, we compute the aborption of the cell and we compute what a streak camera would have recorded if looking at our simulation. The result is shown in Figure 5. We can see that the cell is totally transparent in the cold unperturbed medium, is partially opaque in the precursor and totally opaque in the shock. The ratio between the transmission in the unperturbed medium and the precursor in the simulation is of about 70%. This has to be compared with the value obtained in the experiment which was of 60-70%. This is therefore in good agreement.

4 Conclusion

We have conducted the first experiment at PALS laser facility dealing with radiative shock. The shock propagated in a glass cell filled with xenon at 0.2 bar and the shock propagation was recorded for an unprecedented duration of 40 ns. Using radiation-hydrodynamics simulations, we have shown that the lateral radiative losses greatly affect the precursor propagation. Setting the cell walls transmission to 60% allows to reproduce very well the precursor trajectory and induced brightness constrast recorded during the experiment.

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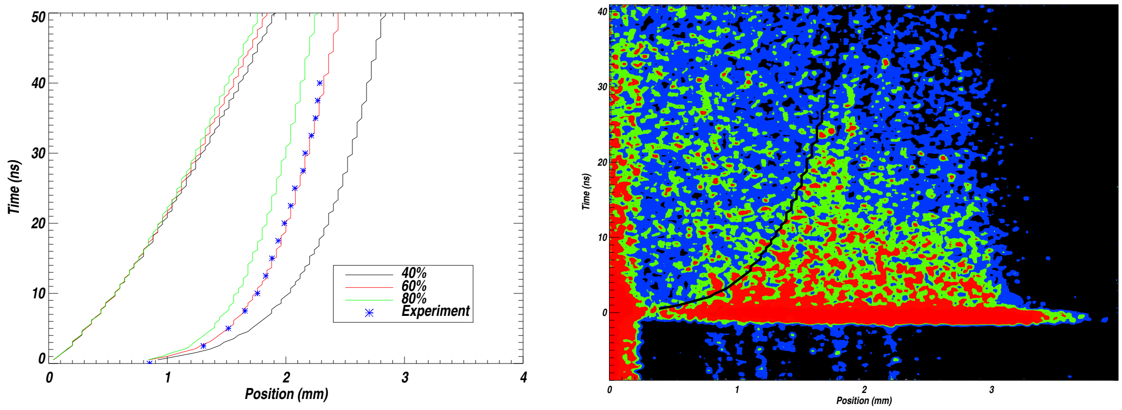

Fig. 4. Left: positions of the shock and the precursor versus time for different values of wall transmission. Right: the precursor position obtained with HERACLES compared to the experimental data.

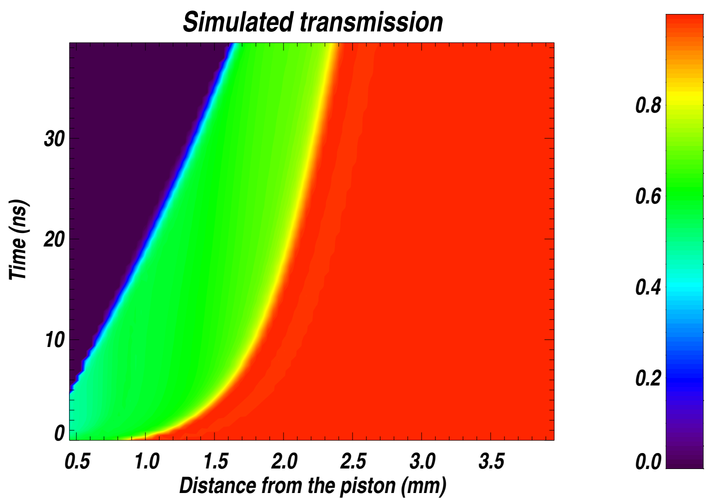

Fig. 5. Simulated transmission of the cell using the HERACLES simulation

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