*32nd EPS Conference on Plasma Phys. Tarragona, 27 June - 1 July 2005 ECA Vol.***29C***, O-2.021 (2005)*

Radiative Shocks: New Experiments for Laboratory Astrophysics

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Introduction and Experimental Set-Up

In the framework of the Laboratory Astrophysics, we present new radiative shocks experiments performed using the LULI2000 facility. A strong shock is driven in a layered piston (CH-Ti-CH) accelerating into a gas cell ($\sim 60km/s$) filled with Xenon at low pressure ($0.1 - 0.3bar$) producing a radiative supercritical shock [1, 4].

To generate a radiative shock, the new high power laser facility LULI2000 of the "Laboratoire d'Utilisation des Lasers Intenses" (LULI) laser (converted at $\lambda = 0.53\mu m$, with a maximum total energy $E_{2\omega} \sim 400J$ in 1.5 ns) focused onto the same focal spot. We used Phase Zone Plates in order to eliminate large scale spatial intensity modulations and obtain a flat-top intensity profile in the focal spot16($\sim 300\mu m$), corresponding to a maximum laser intensity $I_L <= 610^{13} W/cm^2$. A schematic view of the experimental set-up and the target design is shown in FIG. 1.

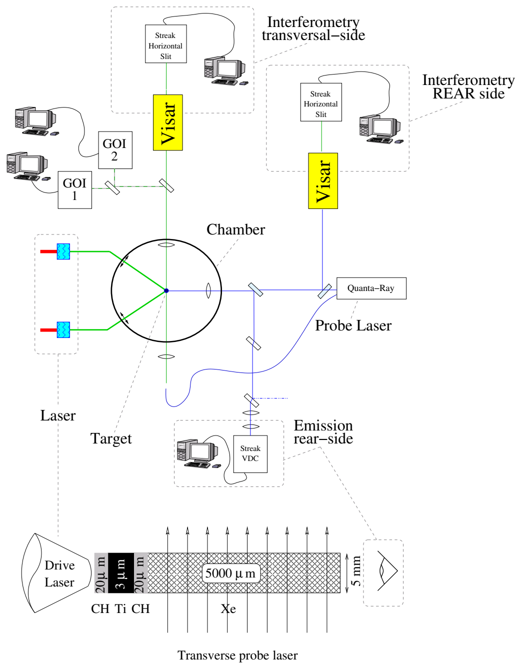

Figure 1: Experimental Set-Up

The two laser beams (on the left in FIG.1) were focused on an ablator-pusher foil ($20\mu m\ CH\ +\ 3\mu m\ Ti\ +\ 30\mu m\ CH$) to generate a shock. Target design was optimized to avoid preheating in the gas.

A low power pulsed laser beam ($8ns - 532nm$) probes the Xenon gas in the transverse direction and is injected into a VISAR and also in two optical framing cameras. These diagnostics allow to measure both precursor and shock velocities along the shock propagation axe [3, 2] as well as the 2D shape of the shock and the precursor.

On rear side, the light emitted from the shocked Xenon is imaged onto the slit of a streak camera. An absolute calibration of the optical system allows to determine the brightness temperature [4]. Data were obtained for different laser intensities and gas pressures. Two VISARs on rear side allowed an accurate measurement of the shock conditions in the pusher up to the breakout in the Xenon.

When the shock breaks out the pusher foil, it propagates into the Xenon gas contained in a 5 mm cubic quartz cell filled at different initial pressures ($P_{Xe} = 0.1 - 0.2 - 0.3 bar$). The typical velocity of the shock in the gas ($50 < D_{Xe} < 60 km/s$) is high enough to fall in a radiative regime and generate a precursor. This velocity can be tuned by varying the laser intensity.

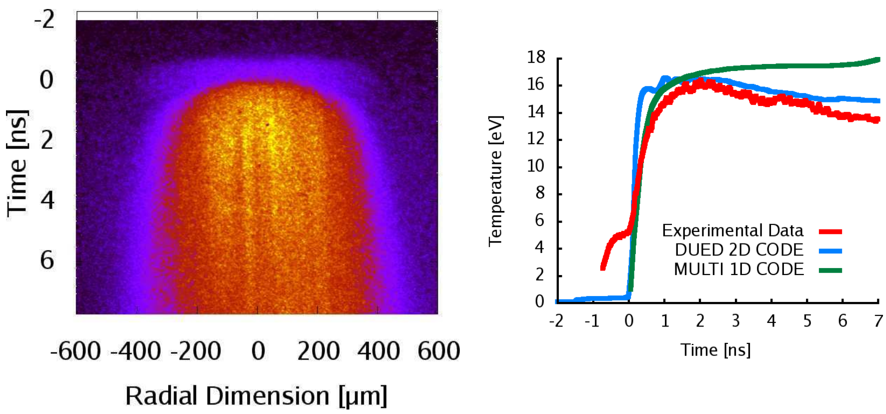

Figure 2: Temperature measurement - 1D and 2D simulations

Comparisons with 1D (MULTI) and 2D (DUED [5]) radiative hydrodynamic codes will be presented for measured quantities (shock velocity, 2D shape, radial expansion, and temperature as well as precursor velocity and precursor electron density).

Rear-Side Diagnostics

Using two VISARs interferometers [3] on the rear side we measured a shock velocity in the precursor of 25 km/s (the corresponding SESAME value for the Temperature of the shock is $T_{Shock} = 6.6 eV$).

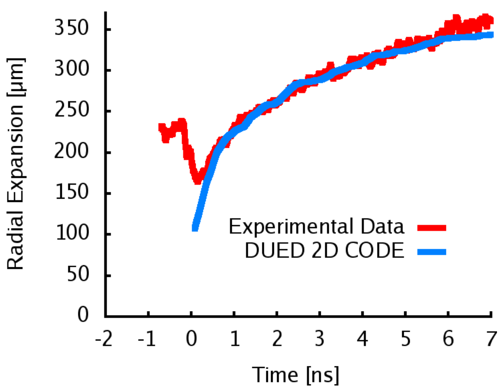

Figure 3: Expansion of the Shock

Among the methods existing for the determination of the temperature, we adopted an absolute photon counting technique. We performed an absolute spectral and energy calibration of the optical system using a white lamp. Then the streak camera itself was calibrated in energy using a low energy ($< 200\ \mu J$) pulsed laser at 532 nm. So we were able to link the total energy emitted by the shock to the CCD counts and thus have a relation between counts and an equivalent blackbody temperature.

In FIG. 2 we present a typical self emission image. We notice a first low emission coming from the pusher ($T_{blackbody} = 5eV$ and a corresponding $T_{graybody} \sim T_{Shock} = 6.3eV$ in perfect agreement with rear side VISARs measurement seen previously.

Then we have the strong emission coming from the Xenon. We compared the values with 1D and 2D with good agreement. Moreover the 2D code follows the "cooling" of the emissive zone for later times. This is due to the radial expansion of the front and we can see in FIG.3 that the 2D code represents very well this expansion.

Transverse-Side Diagnostics

On the transverse side a streak camera was used to probe along the propagation axe. In FIG. 4 we present a typical shot. As we can see fringes disappear as the shock passes by. We can measure then the velocity of the shock. If we look in front of the shock we notice an absorption layer that travels faster than shock. This is a clear signature of the precursor. We can thus plot both velocities versus laser energy (right part of FIG.4). As we can expect, we measured faster velocities for higher laser intensities. We were able to drive a shock in the Xenon at $50-60km/s$ the corresponding precursor velocities are around $75km/s$.

On the same transverse side, two intensified framing cameras (GOI) were in place to take "snapshots" of the shock. We present on the left of FIG. 5 a reference shot ($t = 0$) and on the right the same after $11ns$. We clearly see the shape of the shock and a layer of $200-300\mu m$ of absorbed region. This absorption that we can now estimate (around 30%) is clearly due to a ionized medium in front of the shock (i.e. the precursor).

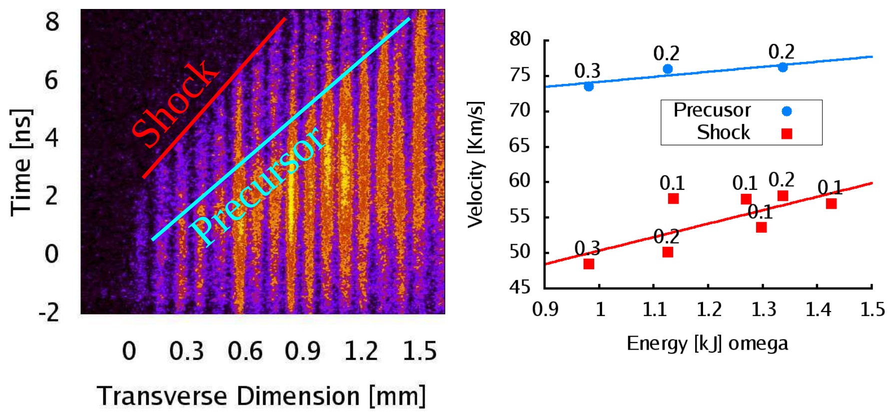

Figure 4: Transverse streak camera

To simulate the absorption in the precursor, we run a 2D simulation and we coupled it with a 3d ray-tracing (the simulation showed a density ρ in the precursor equal to the initial density ρ_0 but with a temperature around $15eV$). What we find is in a good agreement with the experimental data. We can reproduce the total absorption of the shock and the 30% in the precursor layer.

Moreover both shock and precursor shapes are very well represented. This is the first time that we can estimate the precursor temperature.

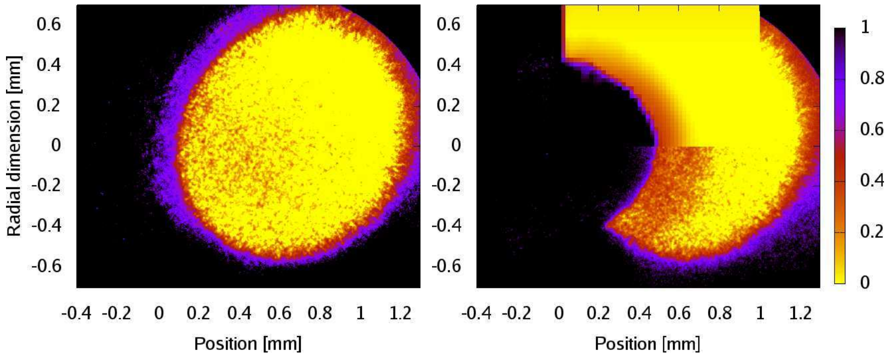

Figure 5: GOI: reference $t = 0ns$ and $t = +11ns$

Conclusions

In conclusion, we have show the signature of a radiative shock using various “simple” optical diagnostics.

The boundary conditions for the radiative shock to develop, have been measure accurately giving robustness to data. On the same shot 6 diagnostics simultaneously collected data both on the shock and on the precursor.

Various parameters have been measured: both shock and precursor velocities, the 2D shapes, the temperature and the radial expansion of the shock. From the absorption of the precursor we have a fist signature of the precursor temperature.

Finally we have pointed out the reliability of ICF codes as task to simulate laboratory experiments relevant to astrophysics.

The authors would like to thanks COST action P14 for the support in STSM

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