Ablative Radiative Shock Experiments

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INTRODUCTION

In astrophysics, the dynamics of interstellar medium is closely linked to the interaction between radiative structures (radiative shock, Marshak wave) and inhomogeneous/clumpy media. One of the most beautiful examples is the Eagle Nebula in M16, otherwise referred to as the Pillars of Creation. This spectacular phenomenon is commonly seen wherever molecular clouds around massive stars (O and B stars). Such hot stars produce intense UV radiation bathing the surface of nearby molecular clouds, causing ablation or photo-evaporation. The absorbing layers become hot and vaporize, in response to which a strong shock compression wave is launched into the cloud. Dense evaporating gaseous globules will evolve in stellar nurseries. Proposed formation mechanisms for such pillars usually involve instabilities at the boundary between the cloud and the ionized region, which grow with time [1-4].

Many other phenomenon involving strong radiative shocks (RS) disturb and inject energy into the interstellar medium, affecting the rate of star formation in galaxies. They are referred to as “feedback mechanisms,” and studying them is critical to understanding galaxy evolution. Therefore, the interaction of strong radiative shock waves with other structures is a central problem in astrophysics, just as it is in inertial-confinement fusion (ICF) where spherical RS have been recently observed in cryogenic implosions [5].

In this new experiment regarding RS, we aimed to observe the interaction of the radiative precursor with a solid object as a mock-up of the ablation processes in molecular clouds or similar objects. To achieve this, we have generated on the GEKKO XII facility, a strong radiative shock in a dedicated gas-cell that lies in the so-called radiative precursor regime, i.e., where Bo < 1 and R >1. We used the long generated precursor to observe its interaction with a solid foil. Optical diagnostics were carefully set up in order to measure all possible parameters related to strong RS. We clearly observed a set in motion of this foil due to absorption of the radiation emitted by the strong RS. From the measured expansion velocity, we inferred the associated temperature that is 1-2 eV.

EXPERIMENTAL SET-UP

In order to study the interaction between a radiation flux and a surface, we used our traditional gas-cell targets specifically built with an obstacle put few millimeters after the radiative shock breaks out the pusher (Fig. 2). This year we have changed how the balloon is
fixed to the target body in order to limit interaction with the radiative flux and the clip along the shock propagation. Another improvement has consisted in increasing the size of the two lateral windows, in order to record unperturbed interferometry fringes as benchmark for non-irradiated gas.

Fig. 2. Target side views showing (left) the Al foil and (right) the hollow-ball situated 2 mm after the pusher (on the left edge of the target) between the two opposite lateral windows.

The radiative shock is generated into the gas by the pusher that is composed of 0.3 µm Al, 25 µm CH, 5 µm Ti. The power-laser energy is converted into mechanical energy by the rocket effect. First, the laser beams interact with the plastic layer (CH) creating a coronal ablation plasma. Second, by conservation of the impulsion a strong compression wave is transmitted in the Ti layer, which prevents X-ray to reach the gas. Third, the strong wave launches the shock into the gas that can become a radiative shock depending on the Mach number achieved. Due to our long experience about radiative shock generation, we have insured that in this experiment the Mach number is sufficiently high to provide radiative effects. In this type of shocks, the Mach number is always up to 100.

All GEKKO XII shots are summarized in Table 1. This year, we performed 12 shots in total and we have recorded excellent measurements due to high-quality diagnostic working. Now we are able to compare all situations using all obstacles and at different laser energies.

<table>
<thead>
<tr>
<th>shot #</th>
<th>beams #</th>
<th>obstacle type</th>
<th>balloon Ø (µm)</th>
<th>gas (50 mbar)</th>
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<tr>
<td>39306</td>
<td>3 @3w</td>
<td>Al foil</td>
<td>-</td>
<td>Xe</td>
</tr>
<tr>
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<td>Si0₂ balloon</td>
<td>465</td>
<td>Xe</td>
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<td>458</td>
<td>Xe</td>
</tr>
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<td>-</td>
<td>Xe</td>
</tr>
<tr>
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<td>6 @3w</td>
<td>Si0₂ balloon</td>
<td>494</td>
<td>Xe</td>
</tr>
<tr>
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<td>-</td>
<td>Xe</td>
</tr>
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<td>1120</td>
<td>Xe</td>
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<td>Xe</td>
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<td>Xe</td>
</tr>
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<td>Al foil</td>
<td>-</td>
<td>He</td>
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<td>462</td>
<td>He</td>
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<tr>
<td>39336</td>
<td>9 @3w</td>
<td>Al foil</td>
<td>-</td>
<td>Xe</td>
</tr>
</tbody>
</table>

EXPERIMENTAL RESULTS

As mentioned previously, this year we have recorded very nice results, especially when the radiative flux interacts with foils. We have imaged the foil expansion both for the rear and front sides due to the heating of radiation. This remarkable effect is clearly seen on data presented in Fig 4, from the shot #39325 using nine laser beams delivering 1.058 kJ.

In Fig. 4 taken at 8 ns after the shock break-out from the pusher, from left to right we see the shadow cone corresponding to the shock extension, then we can follow the fringe deformation indicating heating by irradiation, and 2 mm after there is foil undergoing an extension around the shock propagation axis.

On the GEKKO XII laser facility, we were able to use the large array of visible diagnostics implemented as presented in Fig. 3. First, two interferometry diagnostics: one gated with GOI and one with ICCD3; second, two shadowgraphy recordings, either imaged with IStar or streaked using S20 camera; third, two self-emission diagnostics, one streaked (SOP) using the Optoscope and one snapshot with 4picos.
Fig. 4. Interferometry snapshot taken by ICCD3 at 8 ns.

Fig. 5. Interferometry snapshot taken by GOI at 10 ns.

Fig. 6. Shadowgraphy snapshot taken by IStar at 10 ns.

Now, let us look the foil behavior 2 ns later, i.e. at 10 ns. Two results are in Fig. 5 and 6 that are respectively snapshots taken at 10 ns by GOI on interferometry and by IStar on shadowgraphy. We see very well the shock progression and the big deformation of the Al foil. The most remarkable result is the foil expansion of the rear side almost symmetric than the front expansion.

All these results are under analysis and need comparison with numerical simulations to deduce all physical parameters. The understanding of the radiation flux interaction with SiO2 balloons is more complicated and less visible than the previous case.

However, we have well analyzed the results from the last-year campaign and we have an article [6] ready for submission very soon. The main conclusion of the last-year work is that we report for the first time the clear observation of the interaction of a very strong radiative shock with a solid obstacle. We measured accurately the RS velocities at different conditions up to 140 km/s allowing determining the Boltzmann (Bo) and Mihalas (R) dimensionless numbers [7]. In this experiment, we achieved the intermediate regime as previously described [8]: the radiative flux is much higher than the thermal one, with the radiative energy being not high enough to be in a fully radiative regime. However for the highest velocity (140 km/s) R=25 meaning that we will potentially reach in the future the case where the radiative energy can slightly modify the shock structure (R<5). Moreover, we tried to determine the strength of the radiation flux by positioning the aluminium foil at 2 mm from the main solid pusher target. A clear expansion of the surface toward the shock propagation in xenon is observed with a maximum velocity of 6 km/s.

CONCLUSION

We have now completed the set of shots with different laser energy, using foils and hollow balls (balloon). These experimental results are promising for a deeper understanding of the interaction physics between radiation and solid. One most important result is we can now quantify the shock transmission in the obstacle by the radiation flux. Then, we will extend these physical analyses to the astrophysical context about molecular clouds and their possible gravitational collapse generated by shock transmission into the cloud material, as explained in the Introduction.

ACKNOWLEDGEMENT(S)

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REFERENCE(S)

[6] M. Koenig et al., Interaction of a highly radiative shock with a solid obstacle, to be submitted