Laser driven shock experiments at PALS

D. Batani, H. Stabile, A. Ravasio, T. Desai, G. Lucchini, F. Strati
Dipartimento di Fisica “G. Occhialini”, Università degli Studi di Milano Bicocca and INFM, 20126 Milano, Italy

J. Ullschmied, E. Krousky, J. Skala, B. Kralikova, M. Pfeifer, C. Kadlec, T. Mocek, A. Präg
PALS Research Centre, 18221 Prague 8, Czech Republic

H. Nishimura, Y. Ochi
ILE, Osaka University, Suita City, Osaka 565-0871, Japan
SEQUENCE OF THE TALK

1. Introduction to our work
2. Theme of the experiment:
   Shock pressure in Aluminum
   EOS of Carbon
3. Results and Discussion
   Pressure scaling (Expt & comparison with
   Theoretical models)
   EOS of Carbon
4. Summary
Laser induced shock pressures

Studied from the 70’s. Ambiguity in the earlier works

1. Small laser spots
   - Edge effects
   - Comparison with 1-D models

2. Intensity profile not smooth
   - Hot spots
   - Drilling effects

3. Data missing for short wavelengths at relevant intensity
   - \( P \propto I^{0.3} \) at 0.35 \( \mu \text{m} \) (Key et al., 1983)
   - \( P \propto I^{0.7} \) (theoretical models, 80s’)

- Imp. features of this work:
  - Smooth intensity profile (no hot spots)
  - Large spot (no edge / lateral effects)
Theoretical Models

- C. Max et al. ‘80s, absorption at $n_e \approx n_c$
  \[ P(\text{Mbar}) = 12 \left( I /10^{14} \right)^{2/3} \lambda^{-2/3} (A/2Z)^{1/3} \]

- Caruso & Gratton (Plasma Phys., 10, 867, 1968)
  delocalized absorption ($n_e < n_c$)
  \[ P(\text{Mbar}) = 11.6 \left( I/10^{14} \right)^{3/4} \lambda^{-1/4} (A/2Z)^{7/16} \left( Z^* t /3.5 \right)^{-1/8} \]

- Mora (Phys. Fluids, 25, 1051, 1982)

- Lindl (Phys. Plasmas, 2, 3933, 1995), at $n_e \approx n_c$
  \[ P(\text{Mbar}) = 8.6 \left( I /10^{14} \right)^{2/3} \lambda^{-2/3} \]
Experimental Method

Detection of shock breakout at the rear side of a stepped Al target

The method is direct

It is less prone to 2D effects or relaxation

Al is a standard reference material for shock high pressure experiments (SESAME, QEOS, TEOS)
Experimental set-up
Prague Asterix Laser System
Experimental parameters

PALS laser specifications.
\[ \lambda = 0.44 \ \mu m \ (3 \ \omega) \]
\[ \tau = 450 \ \text{ps}, \ E_L = 400 \ \text{J}. \]
\[ I \approx 2 \times 10^{14} \ \text{W/cm}^2 \]

Target configuration
- Al base = 8 \ \mu m
- Al step = 8.5 \ \mu m
- C step = 9.52 \ \mu m

Optical smoothing technique
- PZP

Diagnostics - Streak camera
- Spatial resolution - 2.6 \ \mu m/\text{Pixel}
- Temporal resolution - 3.22 ps/\text{Pixel}
Phase Zone Plates

Collection of Fresnel lenses with random phases 0 or π
Shock breakout from a flat aluminum target. Image 1.69 ns × 1300 μm
Experimental results (dots)
Scaling law for absorption at $n_c$ (continuous)
De-localized absorption (dotted line).
Discussion

Pressure vs. Intensity shows closer agreement with the de-localized laser radiation approximation.

Corroboration with Theory:
Plasma temp. $\approx 900$ eV (Max, 1985)

$n_e$ at which laser is absorbed $\approx 3 \times 10^{21}$/cc

Assuming an exponential fall $N_0 \approx 40 \ \mu$m from $n_c$. 
Interest of Carbon Study for Planetology

Neptune’s internal structure

- Mantle of Uranus and Neptune = «hot ices» of H₂O, NH₃, CH₄
- Intense, asymmetrical magnetic field (observed by VOYAGER 2)

Existence of a fluid, conducting region?
Grumbach and Martin’s phase diagram and the two Hugoniot curves corresponding to the initial densities $\rho_0 = 1.6 \text{ g/cm}^3$ and $\rho_0 = 1.45 \text{ g/cm}^3$
Targets: Details

SEM image of carbon steps with $\rho_o = 1.45$ g/cm$^3$ deposited on a CHAl substrate. Al steps are not present since they were deposited later.
Determination of a relative EOS point

Interface shock dynamics and impedance mismatch conditions

Process used to find carbon Hugoniot from experimental shock velocities
Shock breakout image from a C / Al target for $E_L = 108$ J.

- $t_0 - t_1$ 205 ps
- $D_{\text{Al}}$ 38.8 km/s
- $P_{\text{Al}}$ 33 Mbar

- $t_0 - t_2$ 295 ps
- $D_{\text{c}}$ 32.2 Mbar
- $P_{\text{c}}$ 18 Mbar
EOS of Carbon

Experimental EOS results from shock experiments. Only data with pressures $P > 1.5$ Mbar and corresponding Hugoniot are shown. Our points: **full squares**, $1.45 \text{ g/cm}^3$ LUL I; empty circles, $1.6 \text{ g/cm}^3$ LUL I; full circles, $1.6 \text{ g/cm}^3$ PAL S. Previous points: empty diamond, $1.85 \text{ g/cm}^3$ Pavlovskii et al. [28]; **triangles**, $2.2 \text{ g/cm}^3$ Nellis [29]; **full diamond**, $2.23 \text{ g/cm}^3$ Pavlovskii et al. [28]; empty squares, $3.51 \text{ g/cm}^3$ (diamond) Pavlovskii [30].
Conclusions

- Laser induced shock pressures on Al was measured at 0.44 µm, $I=10^{14}$ W/cm$^2$ with large spot and PZP.

- P scaling with Intensity shows good agreement with de-localized absorption model

- EOS of Carbon has been measured in the Mbar pressure range

- A deviation from SESAME is present at high pressure.