Laser driven shock experiments at PALS

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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 μm (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 $n_e \approx n_c$**

  $$P\,(\mathrm{Mbar}) = 12\,(I/10^{14})^{2/3}\,\lambda^{-2/3}\,(A/2Z)^{1/3}$$

- **Caruso & Gratton** (Plasma Phys., **10**, 867, 1968)
- **Mora** (Phys. Fluids, **25**, 1051, 1982)

  delocalized absorption ($n_e < n_c$)

  $$P(\mathrm{Mbar}) = 11.6\,(I/10^{14})^{3/4}\,\lambda^{-1/4}\,(A/2Z)^{7/16}\,(Z^*\,t/3.5)^{-1/8}$$

- **Lindl** (Phys. Plasmas, **2**, 3933, 1995), **at $n_e \approx n_c$**

  $$P(\mathrm{Mbar}) = 8.6\,(I/10^{14})^{2/3}\,\lambda^{-2/3}$$

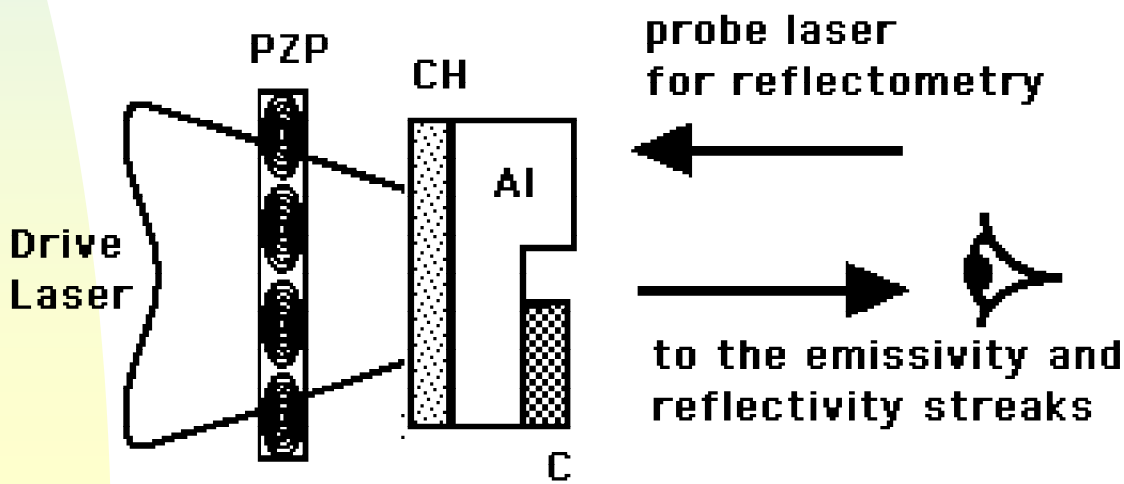
Experimental Method

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

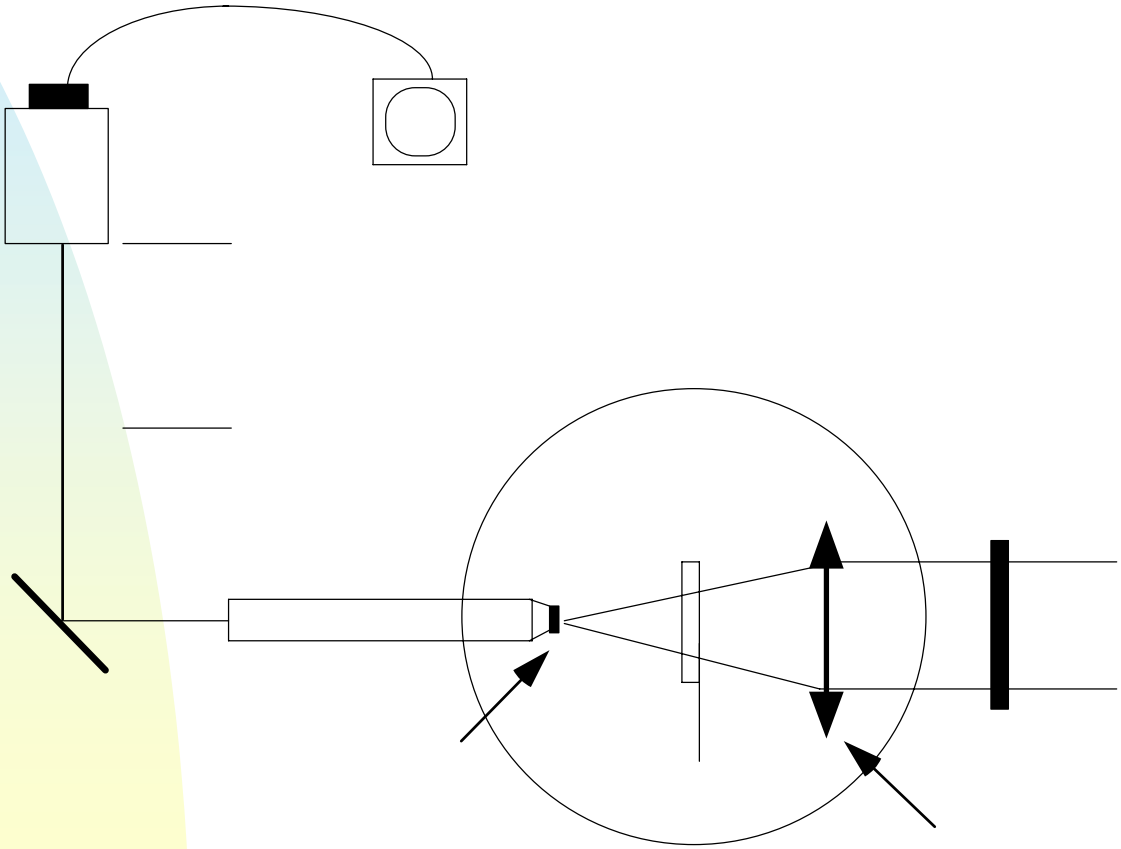
The method is direct

It is less prone to 2D effects or relaxation

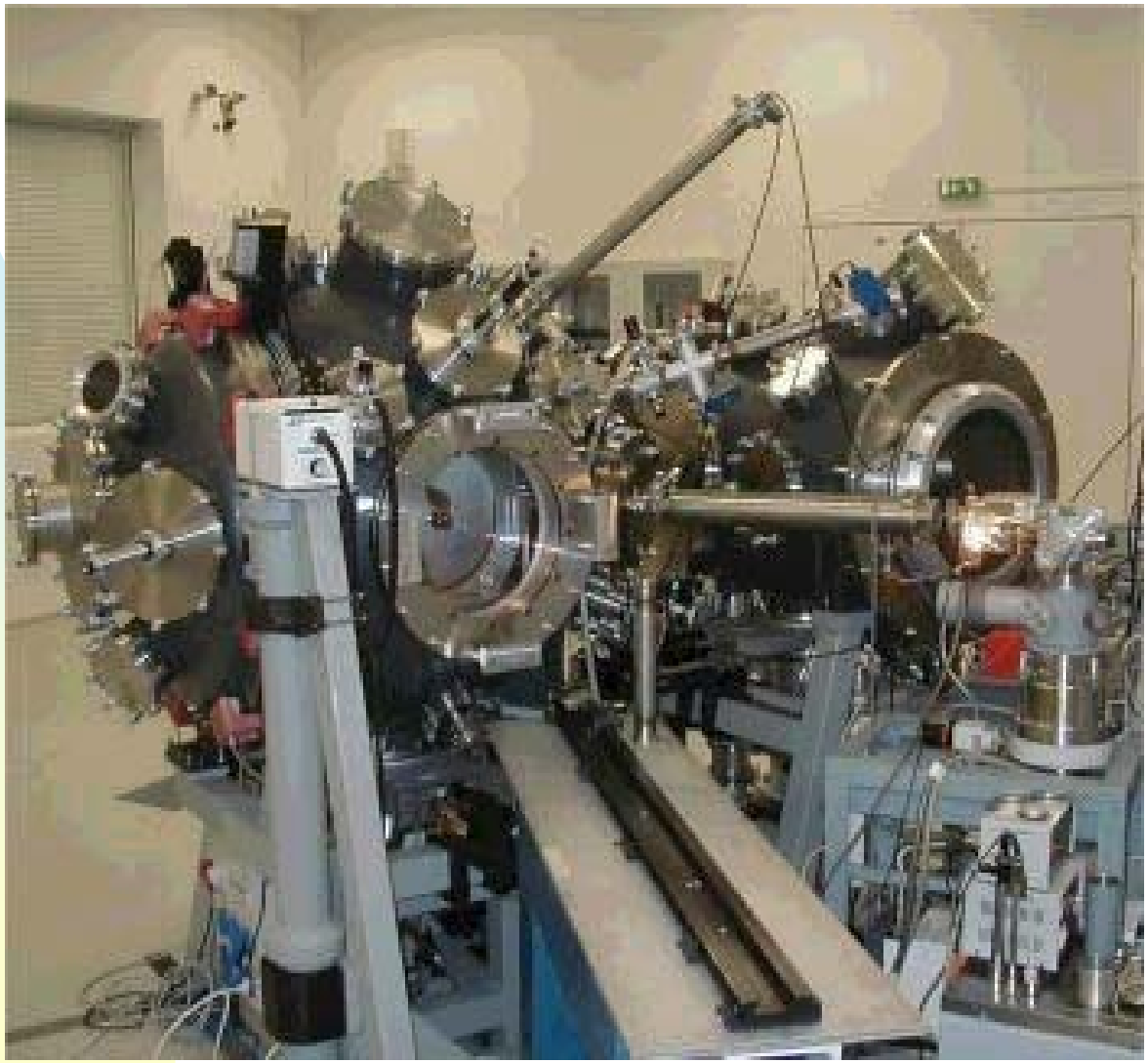
Al is a standard reference material for shock high pressure experiments (SESAME, QEOS, TEOS)



Experimental set-up



Prague Asterix Laser System



Experimental parameters

PALS laser specifications.

λ = 0.44 μm (3 ω)

τ = 450 ps, E_L = 400 J.

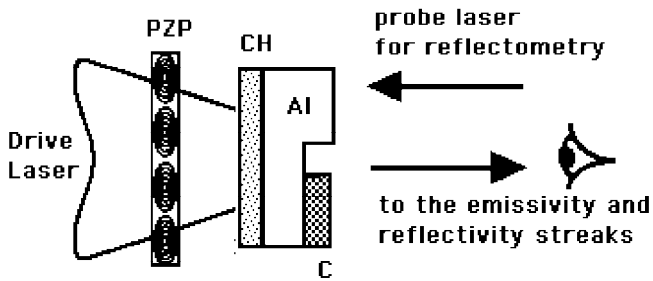
I $\approx 2 \times 10^{14}$ W/cm^2

Target configuration

Al base = 8 μm

Al step = 8.5 μm

C step = 9.52 μm



Optical smoothing technique

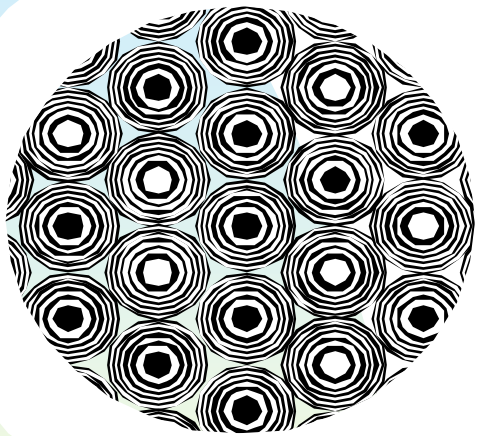
PZP

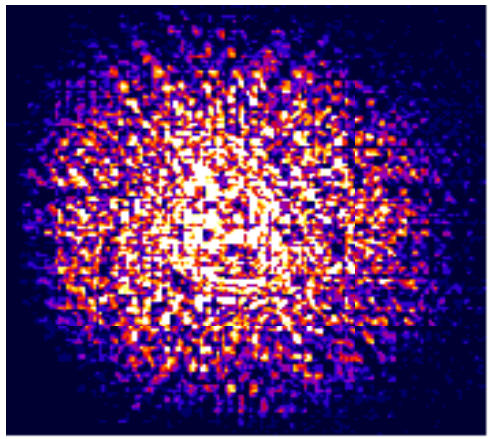
Diagnostics- Streak camera

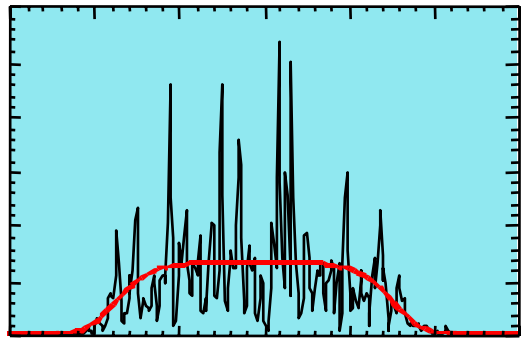
Spatial resolution - 2.6 μm/Pixel

Temporal resolution - 3.22 ps/Pixel

Phase Zone Plates





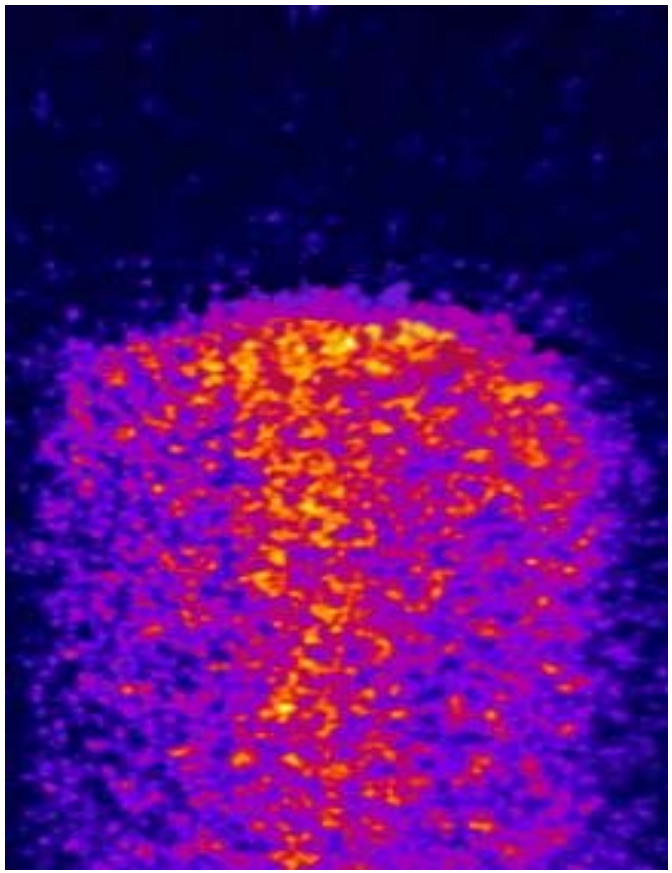


250 μm

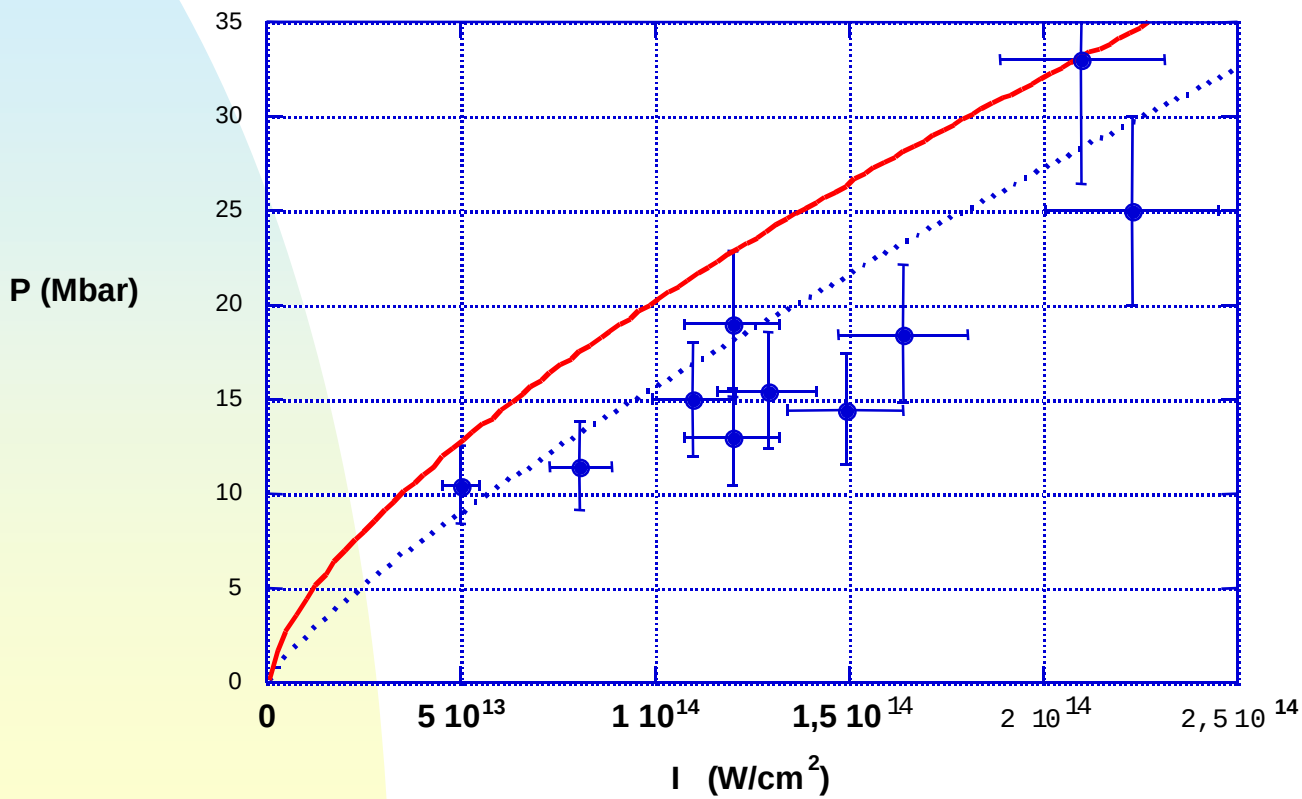
Focal spot

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 (continous)
De-localized absorption (dotted line).



Discussion

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

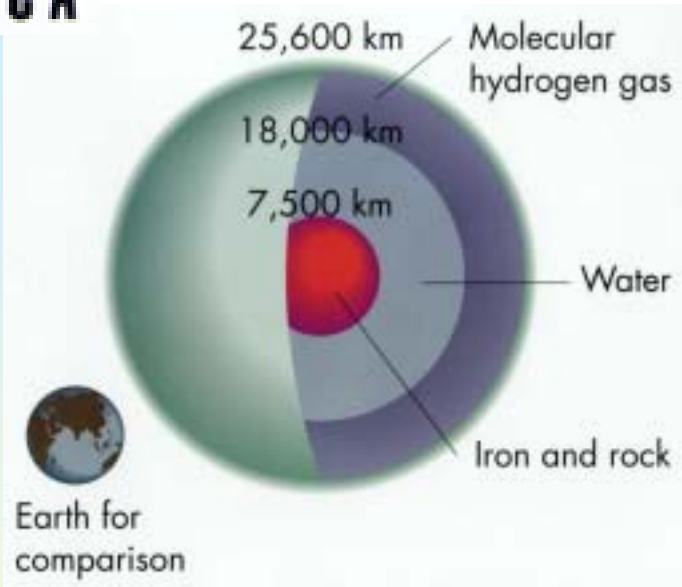
Corroboration with Theory:

Plasma temp. ≈ 900 eV (Max, 1985)

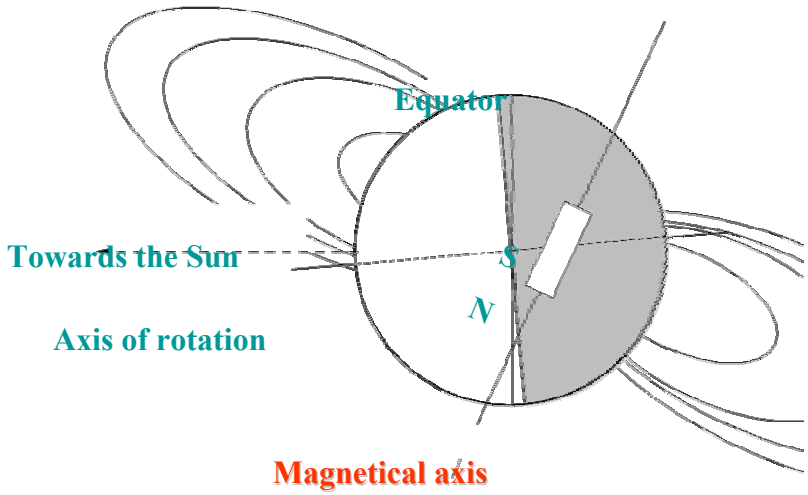
n_e at which laser is absorbed ≈ 3 x 10^{21}/cc

Assuming an exponential fall N_o ≈ 40 μm from n_c.

Interest of Carbon Study for Planetology



Neptune's internal structure

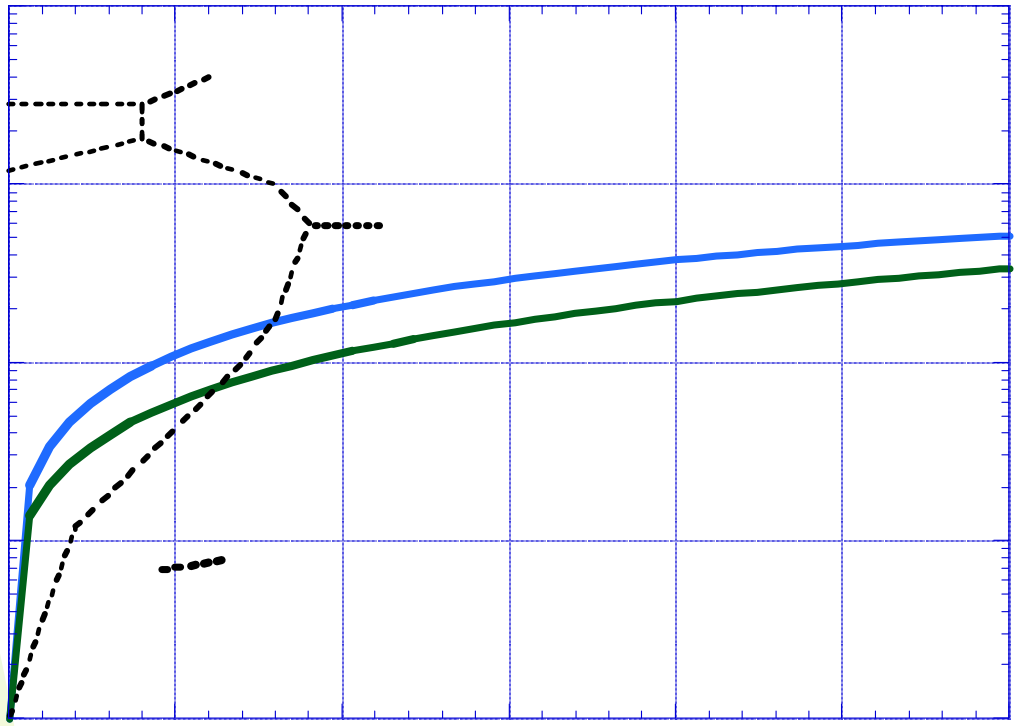


Magnetic field of Uranus

- Mantle of Uranus and Neptune = «hot ices» of H_2O, NH_3, CH_4
- Intense, asymetrical magnetic field (observed by VOYAGER 2)

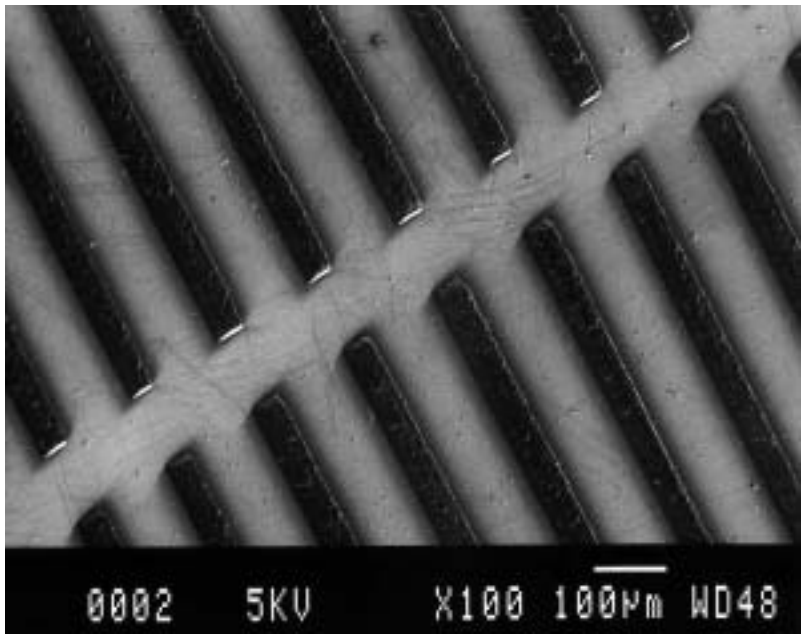
Existence of a **fluid, conducting** region ?

EOS of Carbon



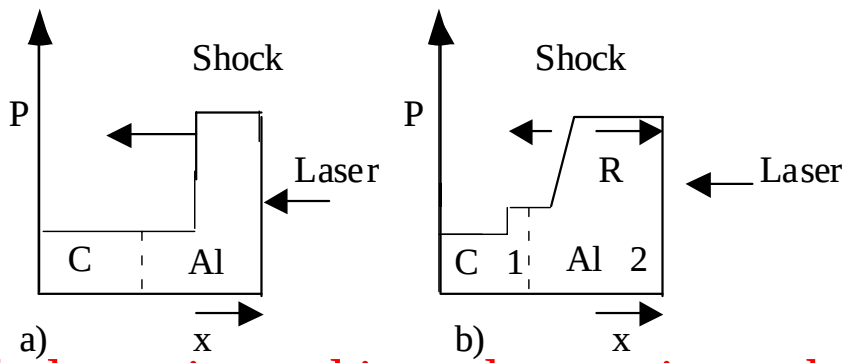
Grumbach and Martin's phase diagram and the two Hugoniot curves corresponding to the initial densities $\rho_o = 1.6\ g/cm^3$ and $\rho_o = 1.45\ g/cm^3$

Targets: Details

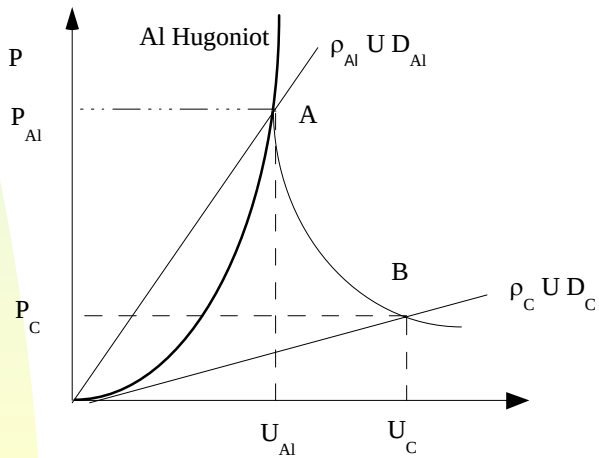


SEM image of carbon steps with ρ_o = 1.45 g/cm^3 deposited on a CH/Al substrate. Al steps are not present since they were deposited later

Determination of a relative EOS point

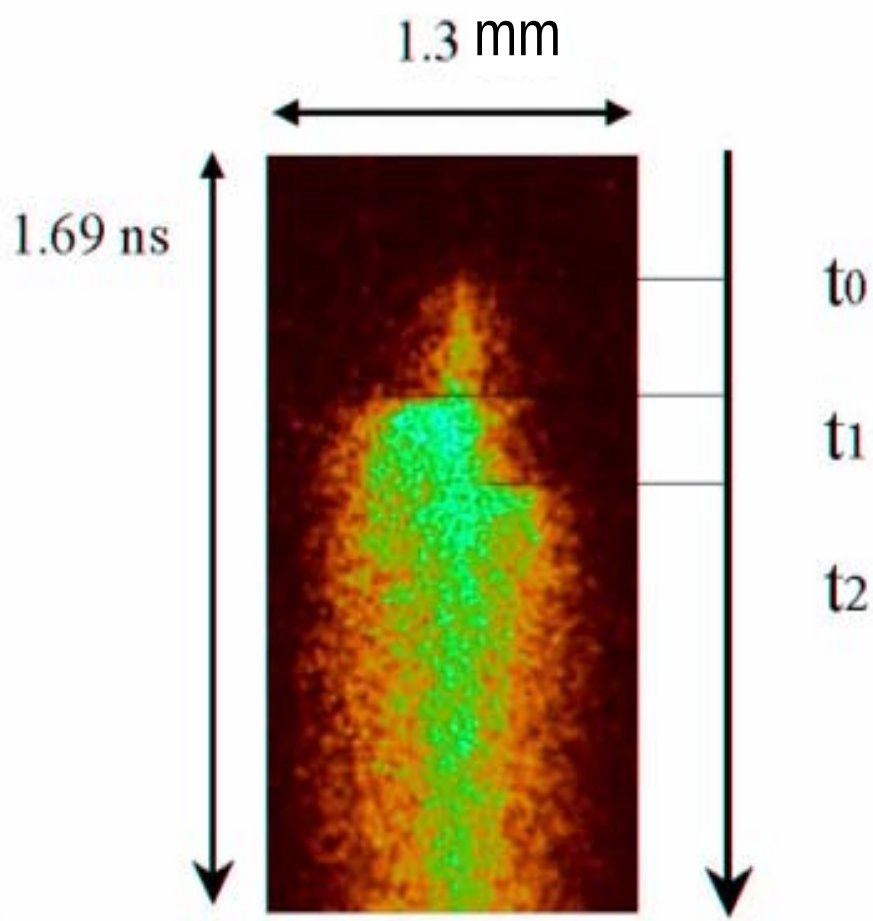


Interface shock dynamics and impedance mismatch conditions



Process used to find carbon Hugoniot from experimental shock velocities

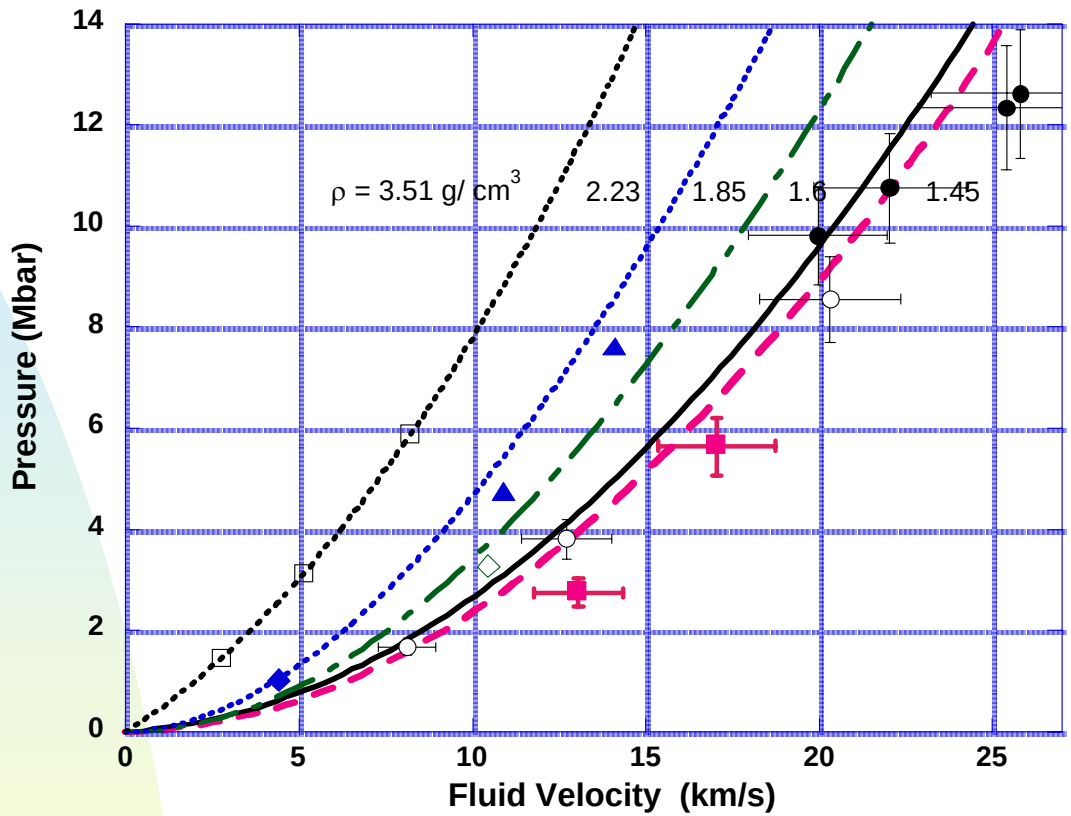
Shock breakout image from a C / Al target for E_L = 108 J.



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

t_0 - t_2 295 ps
D_c 32.2 Mbar
P_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 g/ cm^3 LULI; empty circles, 1.6 g/cm^3 LULI; full circles, 1.6 g /cm^3 PALS. Previous points: empty diamond , 1.85 g/ cm^3 Pavlovskii et al. [28]; triangles, 2.2 g/ cm^3 Nellis [29]; full diamond, 2.23 g/ cm^3 Pavlovskii et al. [28]; empty squares, 3.51 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 meaured in the Mbar pressure range**
- **A deviation from SESAME is present at high pressure.**