Experimental investigation of solid-vapour phase transitions in metals during shock release

P. Allan*, M. R. Betney, T. J. Ringrose, L. Donora, N. Chaturvedi,
J. Skidmore, G. C. Burdiak, P. Foster, H. I Poole and H. W. Doyle
*peter.allan@firstlightfusion.com

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Motivation

- First Light Fusion is researching ICF with novel target designs utilising strong shocks driven by hyper-velocity projectiles and EM launch systems.
- Target designs are being developed using our front tracking hydrodynamics code Hytrac.
- Phase of shock compressed solids releasing into gas is of particular interest
- A solid subject to a strong shock can melt, partially or fully, either on compression or release from the shocked state (see Fig. 1)
- Phase of released material depends on a number of factors (shock speed, ambient density, etc.) and can be in a mixed state
- Fragmentation can also occur (spallation)
- In the case of a shock propagating through a solid-gas interface, i.e. pusher compression of a D_2 fill, the state of the releasing solid and its evolution will govern the implosion dynamics of the fuel
- Experiments will provide integrated test of hydrocode and equation-of-state models

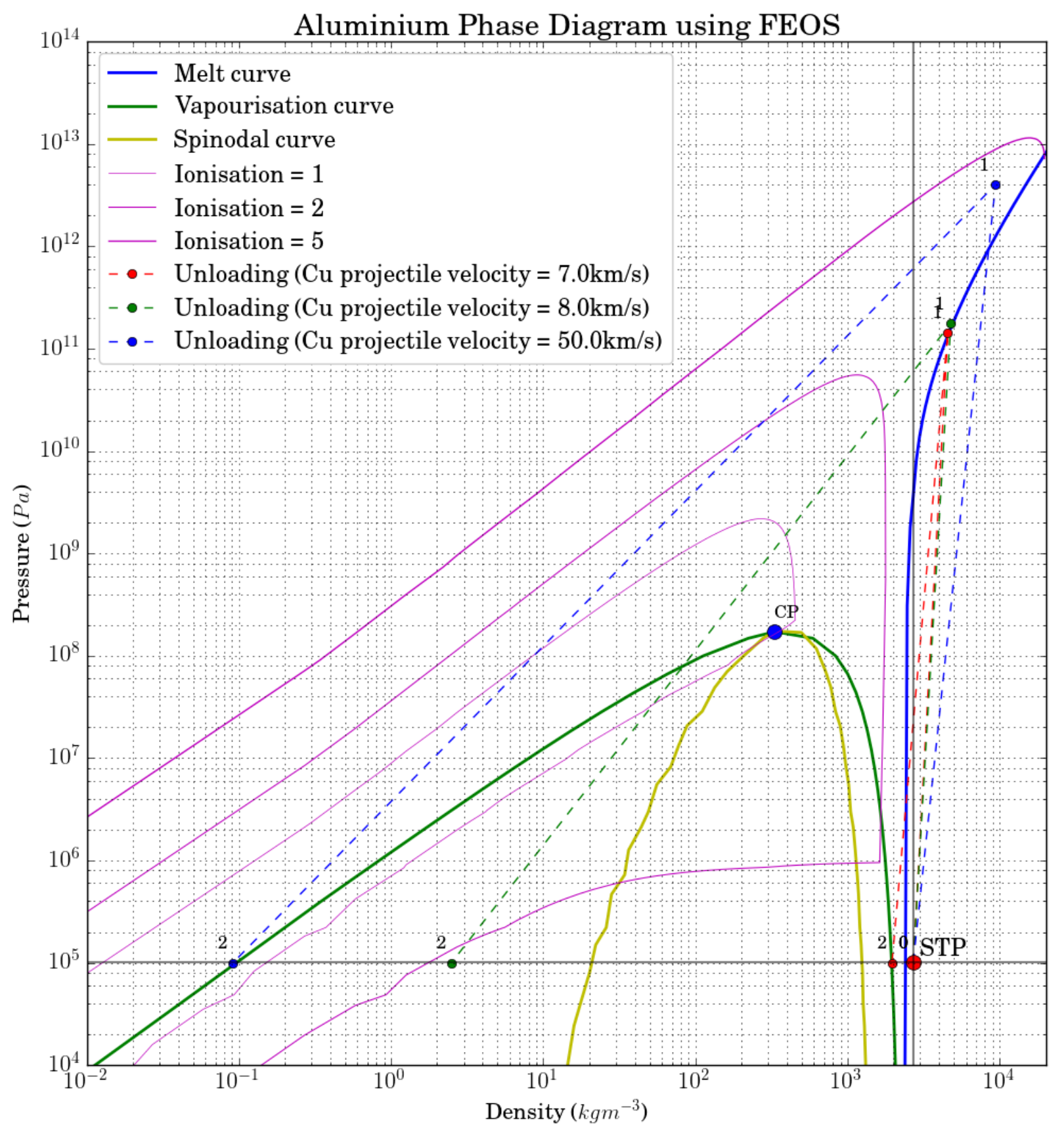
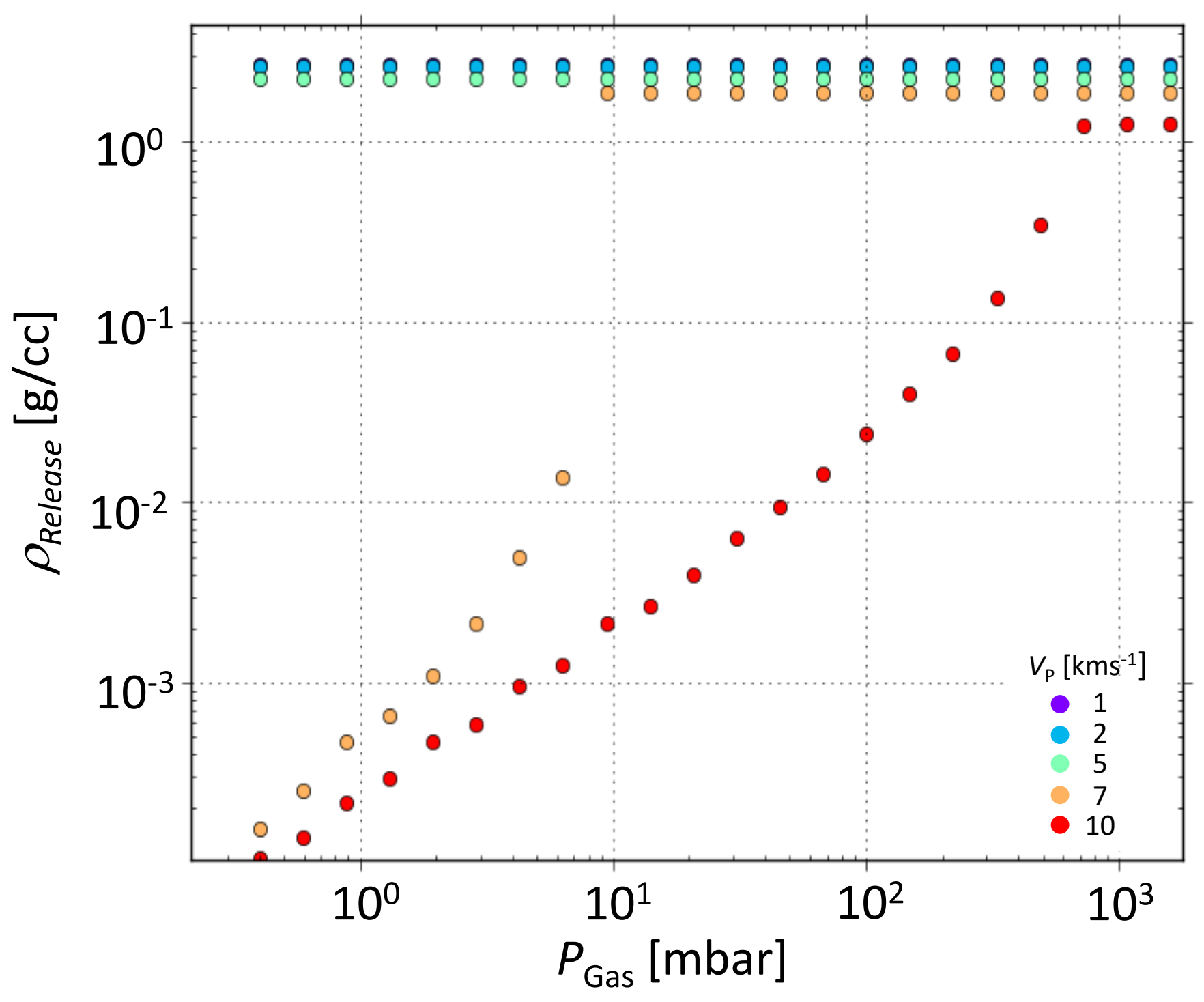


Fig. 1: Aluminium phase diagram (FEOS). Cu projectile impacting solid Al releasing into 1 bar D_2

Simulations



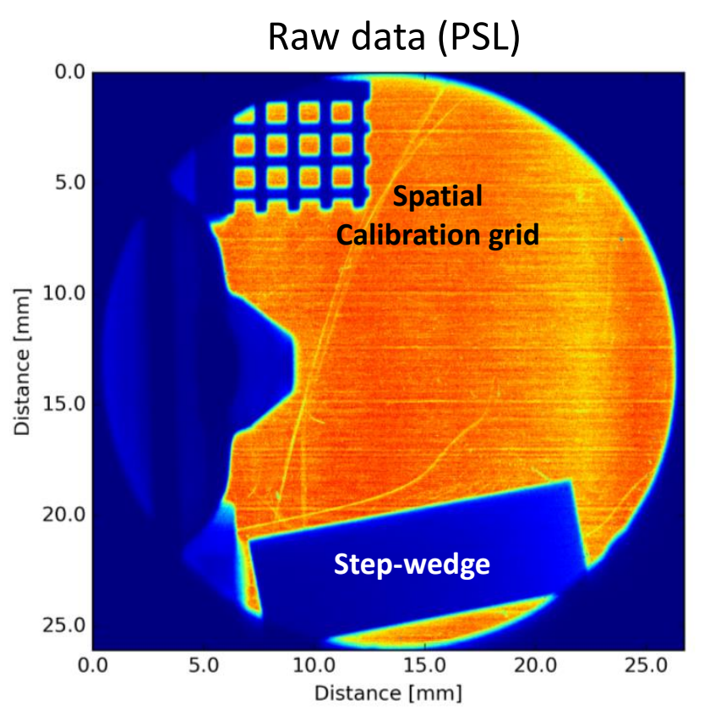
- Solve simple 0D Riemann problem to study effect of incident projectile velocity and ambient gas pressure on instantaneous release density of various materials (Fig. 2)
- Materials modelled with FEOS
- Release density strongly dependent on both ambient pressure and shock velocity
- Threshold exists for releasing to rarefied states
- 1D and 2D simulations used to inform target hydrodynamics: predict release density profiles and diagnostic timings

Fig. 2: Al release density as a function of ambient gas pressure and incident projectile velocity in kms^{-1}. Projectile material was Cu.

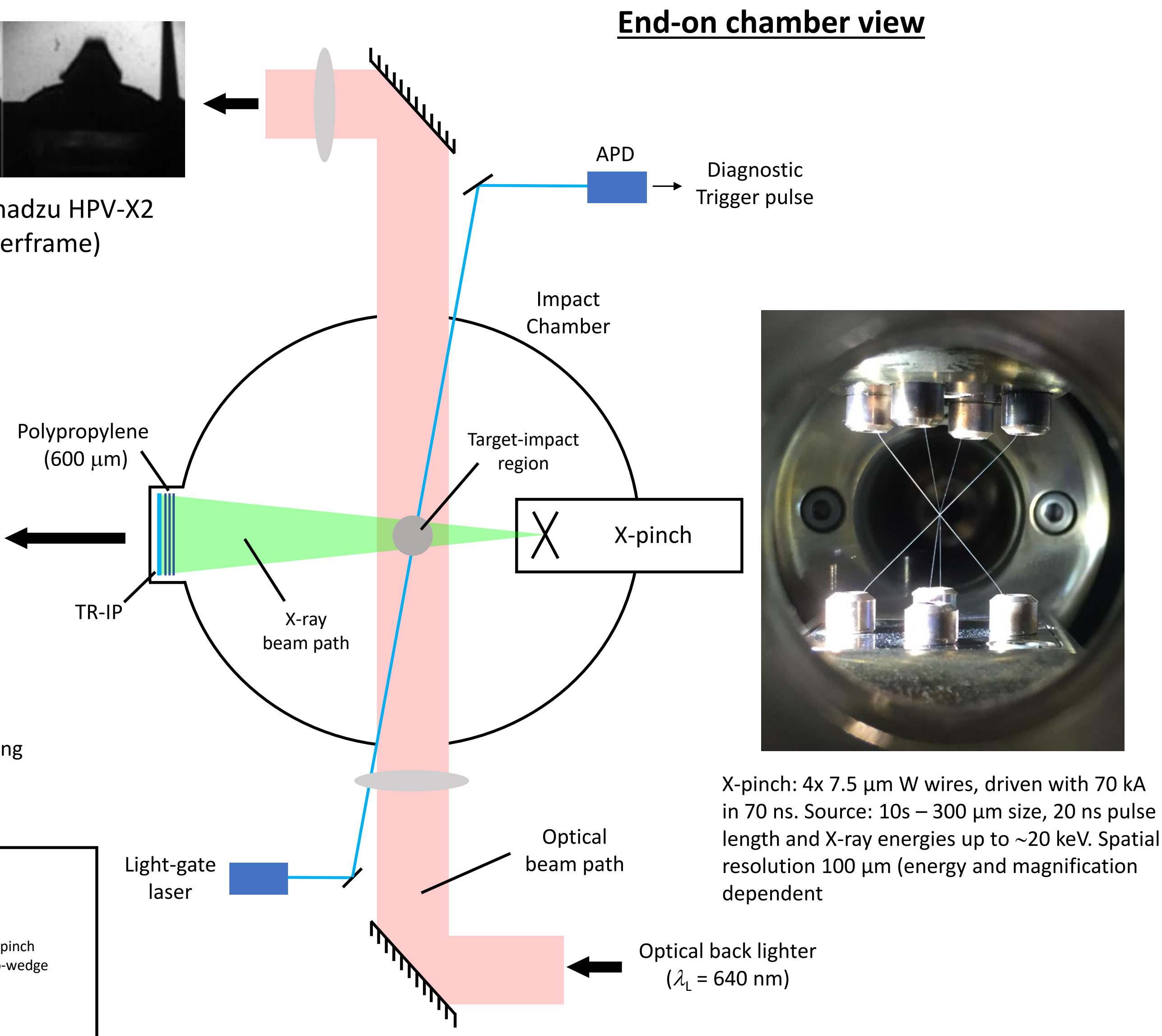
Experimental Setup

- Performed 12 shots using FLF's two-stage light gas gun (2SLGG) [1]
- Cu projectile ($V_P = 4.7 – 6.8\ \text{kms}^{-1}$) was used to drive a planar shock into thin (1-2 mm thick) Al and PMMA foils
- Simultaneous, orthogonal optical and x-ray backlighting to diagnose projectile velocity, release speed and density of released material

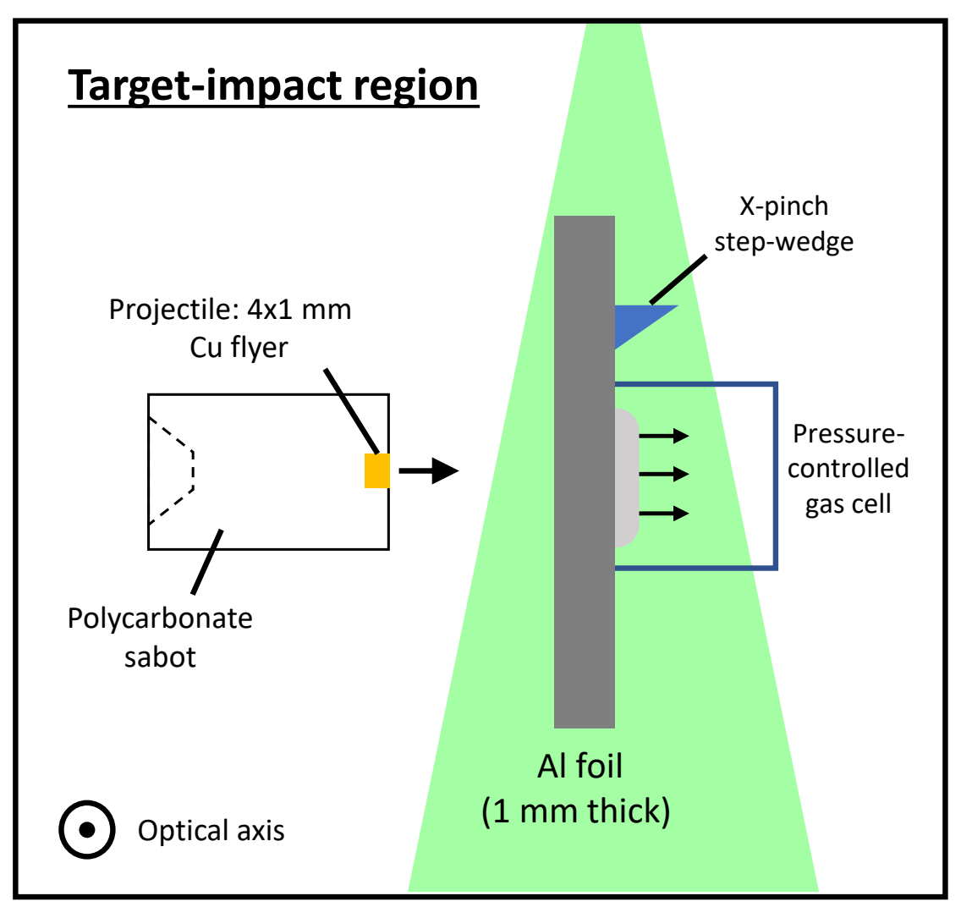
Optical framing camera – Shimadzu HPV-X2
(50 ns exposure, 50 ns interframe)



X-pinch radiograph: Cu projectile impacting an Al layer



X-pinch: 4x 7.5 μm W wires, driven with 70 kA in 70 ns. Source: 10s – 300 μm size, 20 ns pulse length and X-ray energies up to ~20 keV. Spatial resolution 100 μm (energy and magnification dependent



- Initial target design had no gas cell - pressure dictated by the ambient chamber pressure
- Later designs incorporated an Ar filled gas-cell which allowed pressure control

1. Ringrose et al. Procedia. Eng. 204 (2017)

Shock release in PMMA

- Polycarbonate projectile into PMMA
- No pressure control (ambient chamber pressure)
- Shock velocity significantly alters release density profile (see Fig. 3)
- Lateral size of release region too large for X-pinch FOV – Abel inversion of data not possible

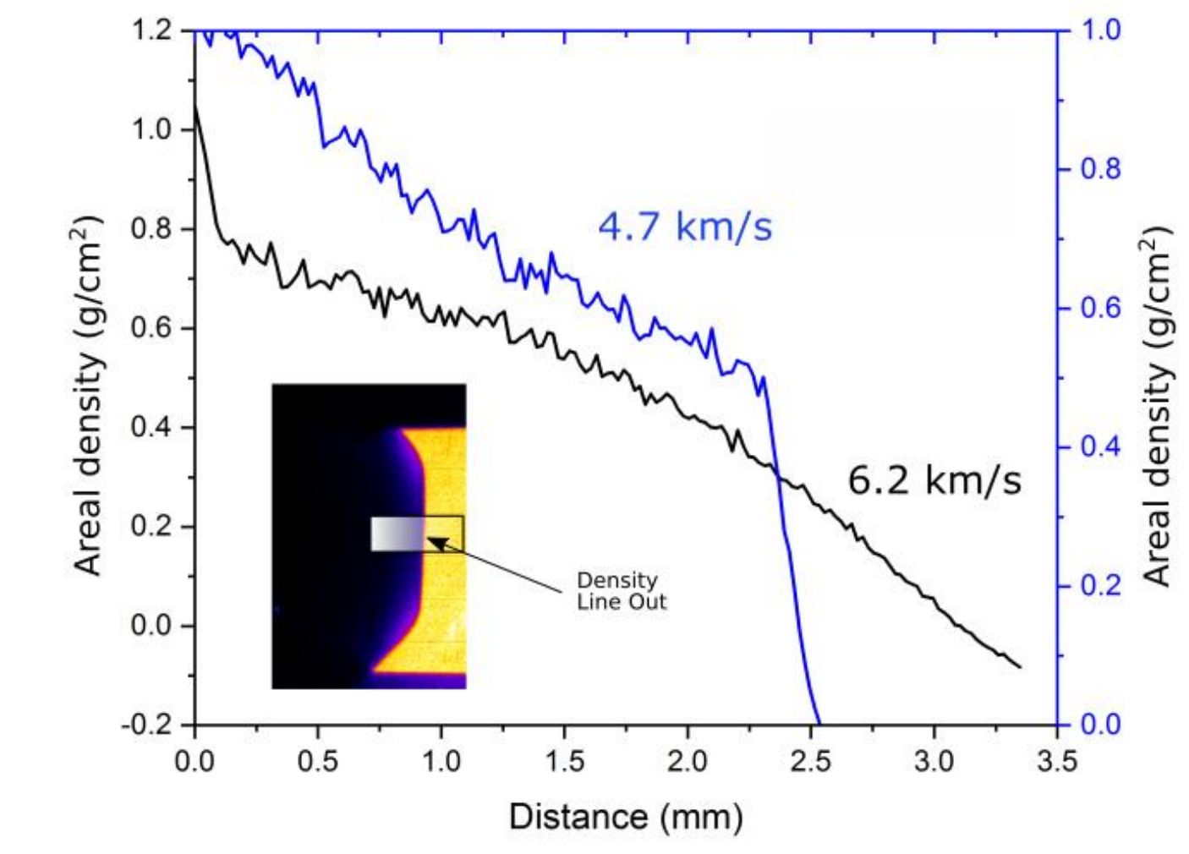


Fig. 3: Areal density profiles for 1 mm thick PMMA foils impacted by a polycarbonate projectile at 2 velocities

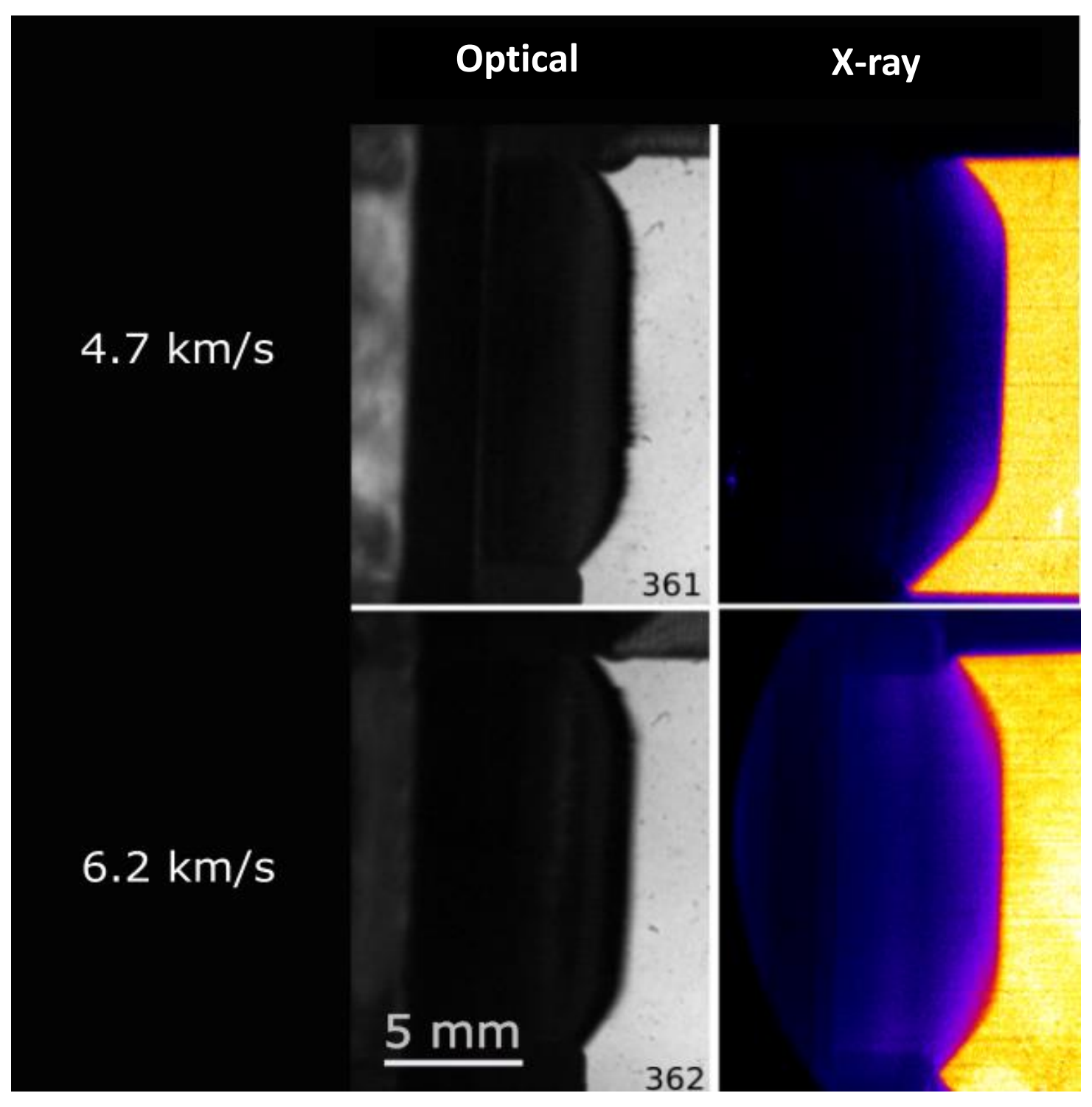


Fig. 4: Optical and x-ray radiographs of the released PMMA

Shock release in Al

- Cu flyer (4x1 mm) into 1 mm thick Al foil
- Release into ambient chamber pressure
- Reduced flyer size reduces lateral extent of released material – quantify path length – Abel invert to produce density map
- Abel inversion requires release to be axially symmetric and the spectral attenuation to be well characterised

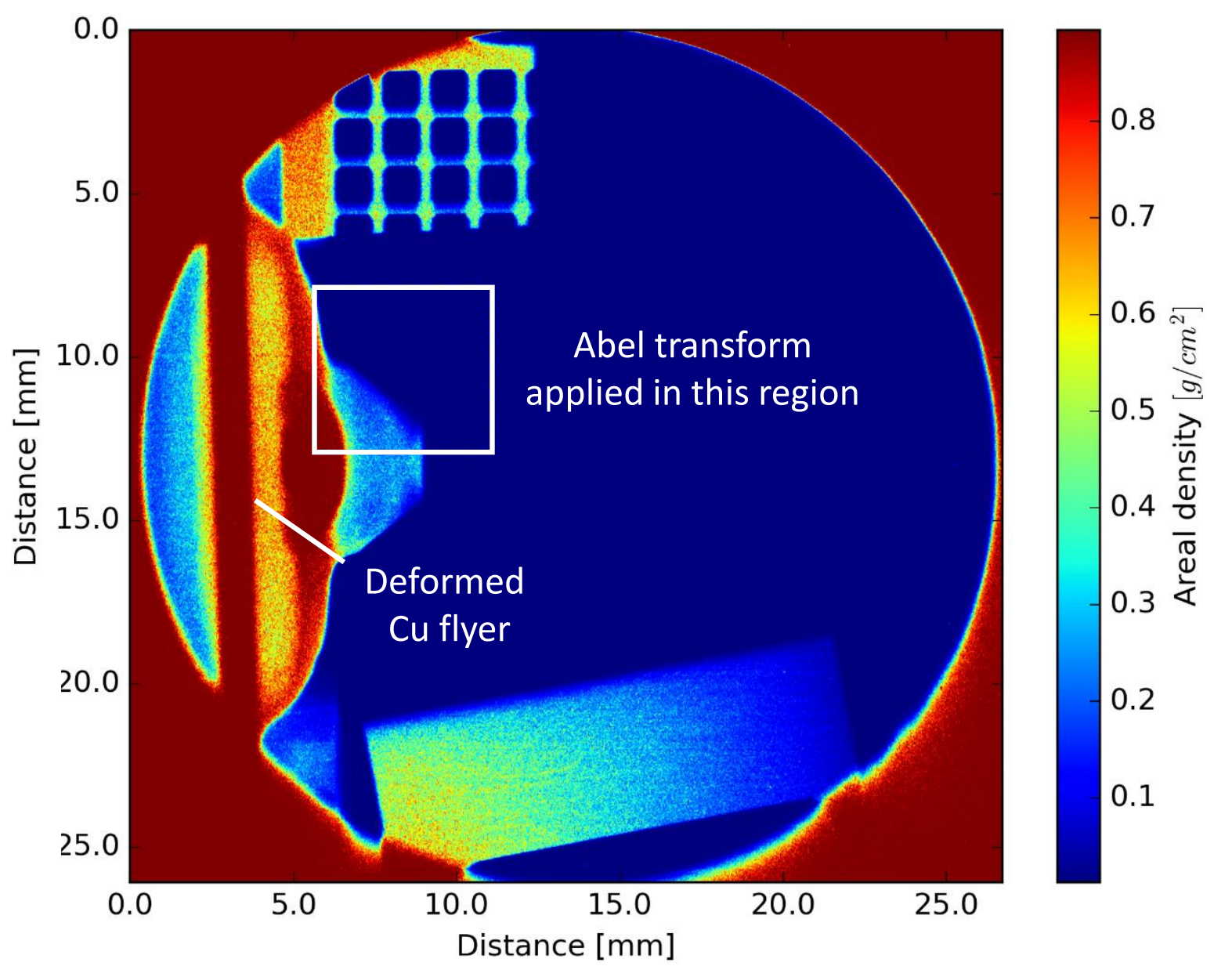


Fig. 5: Areal density map of shock-released Al

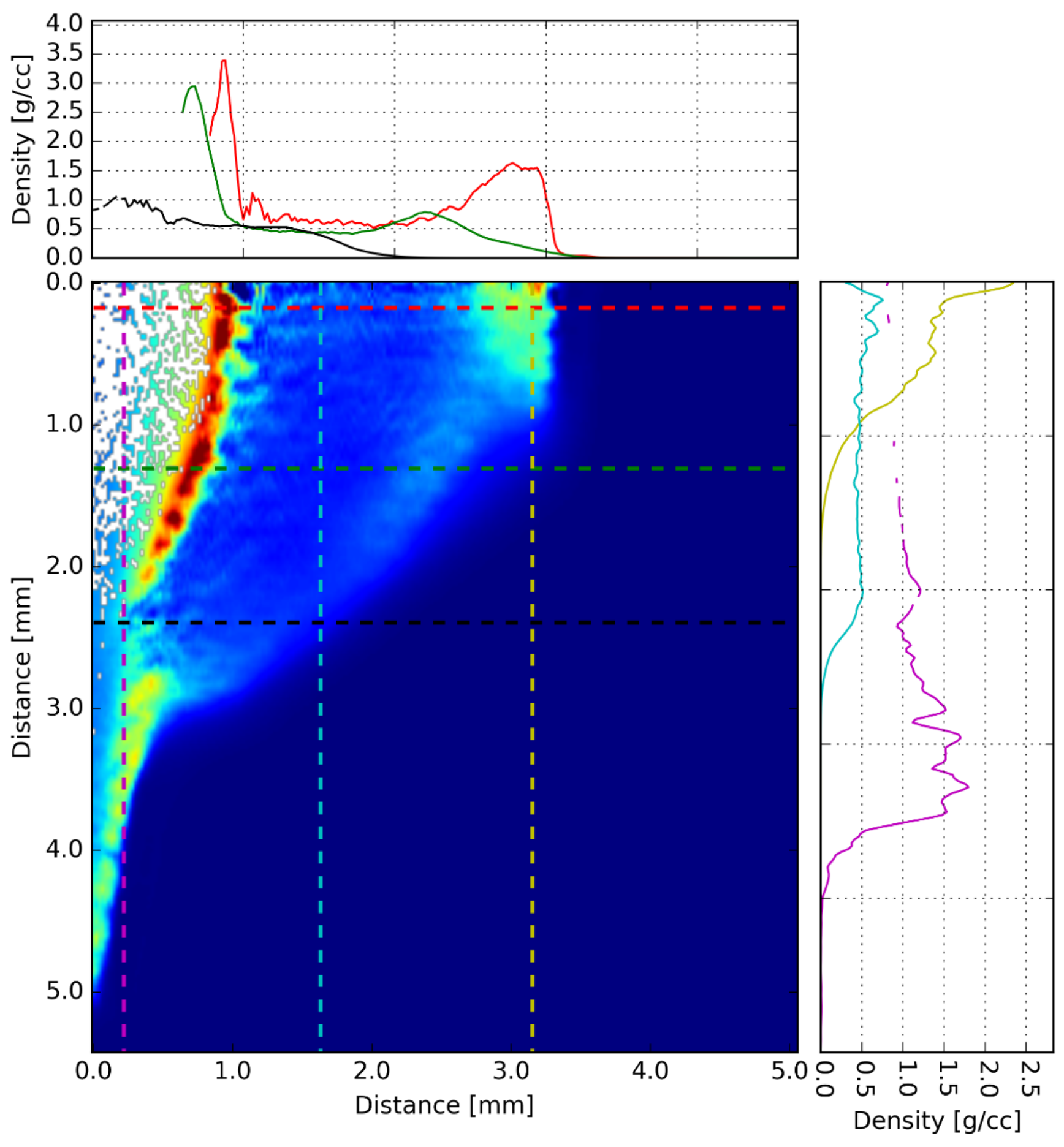


Fig. 6: Abel transformed density map of shock-released Al. See Fig. 5 for region of radiograph. White regions sample is opaque to back lighter x-rays.

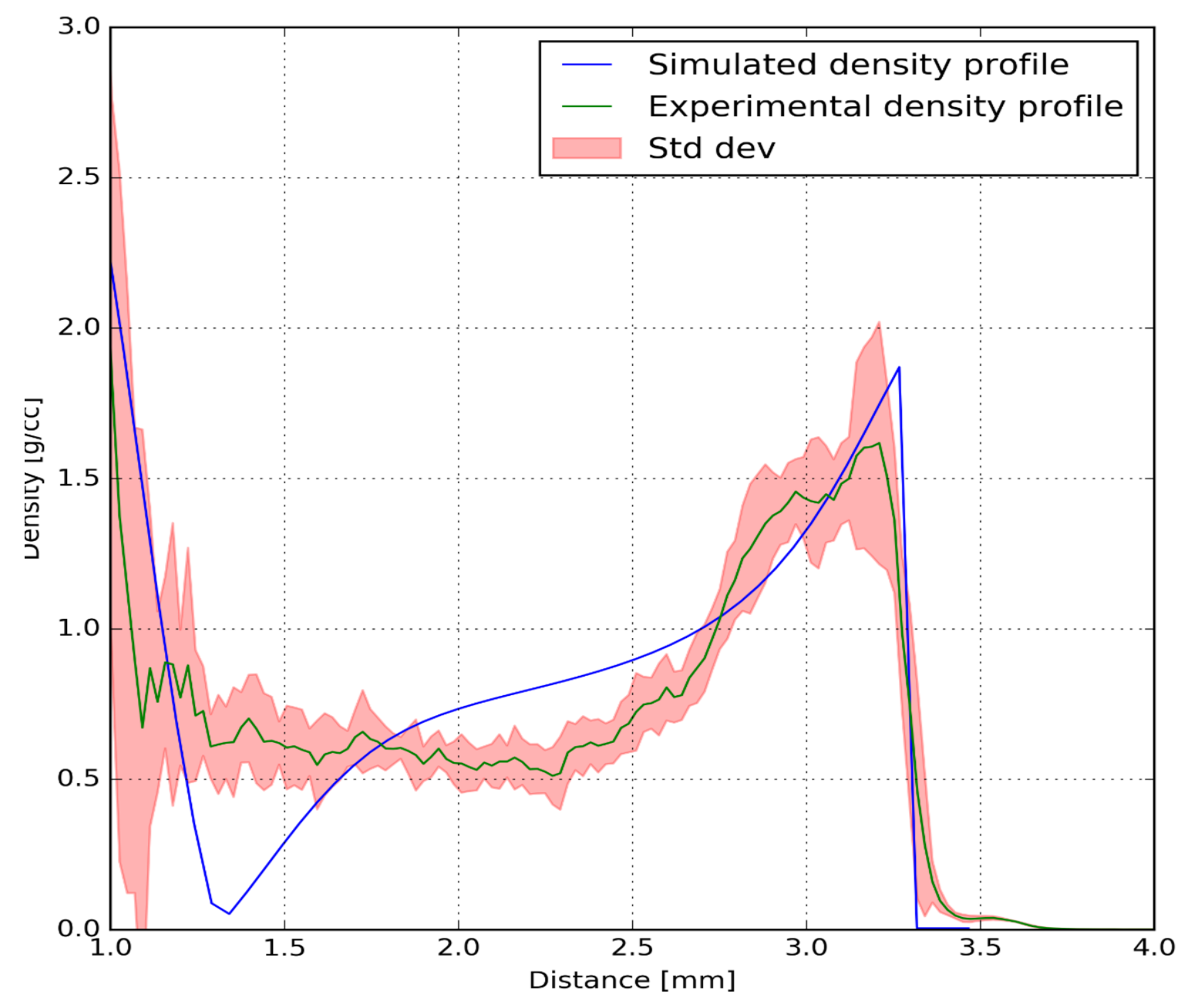
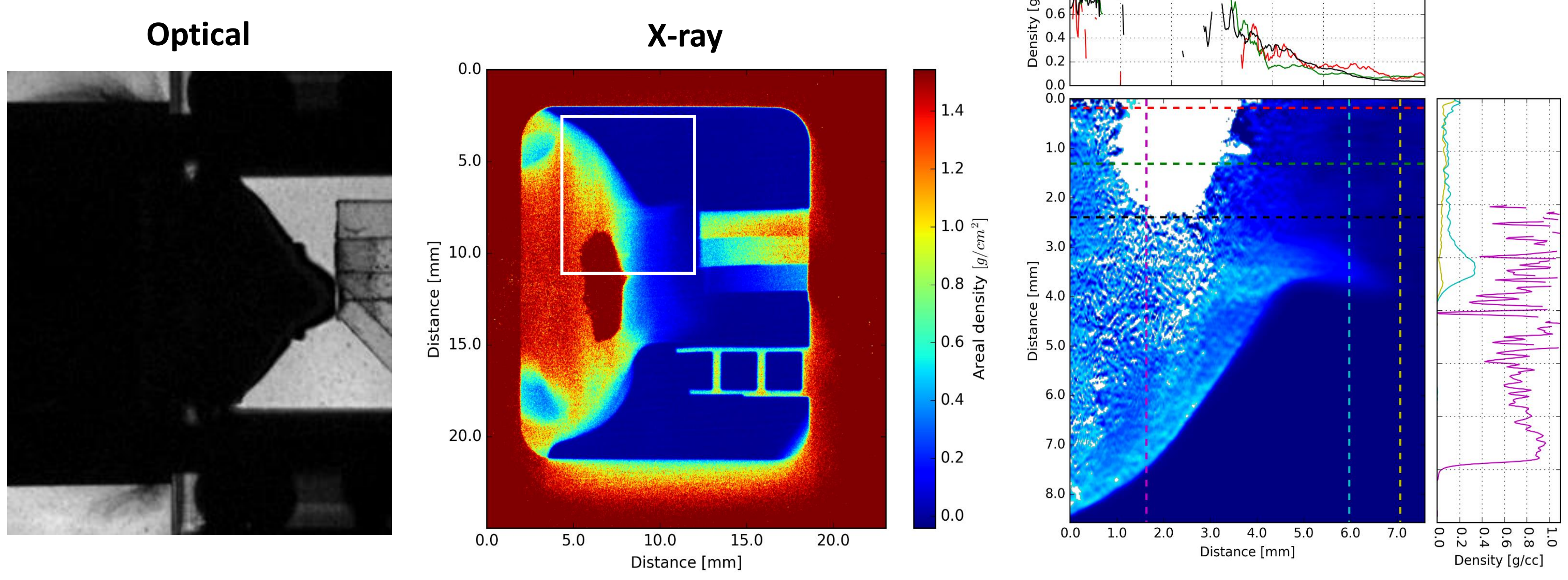


Fig. 7: Comparison of experiment and Hytrac prediction at t = 500 ns.

- Significant internal structure in the released material
- Good agreement between experiment and Hytrac + FEOS prediction
- Discrepancy at Cu-Al interface
- Data suggests release is in a mixed phase with spallation at leading edge of release

Current work and conclusions

- Recently performed experiments on shocked PMMA with an Ar filled gas cell (see experimental setup)
- Currently analysing data and performing simulations
- Significant differences between optical and X-ray



- Demonstrated experimental platform and diagnostic capability to study and diagnose the phase of shock-released material
- Good agreement between experiment and Hytrac prediction