Radiography of gas-gun impact experiments using an X-pinch

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first light

Motivation

- First Light Fusion (FLF) is researching ICF target designs that utilise strong shocks driven by high-velocity projectiles and EM launchers.
- Target designs are being developed and understood using our in-house front tracking hydrodynamics code Hytrac.
- Hydrodynamics experiments are performed to benchmark the code and our equation of state models.
- These experiments generate conditions opaque to probing with optical light.
- X-ray radiography of the dynamic density structures occurring during target impacts has been achieved by coupling an X-pinch x-ray source to the FLF two-stage light gas-gun [1].

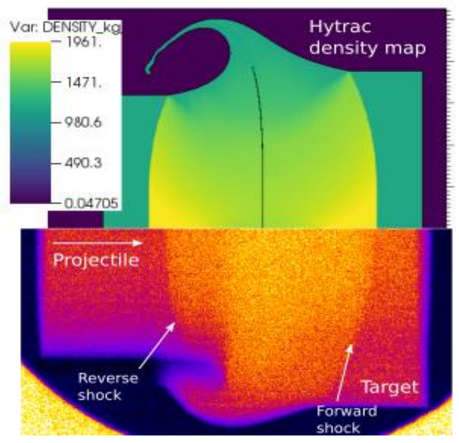
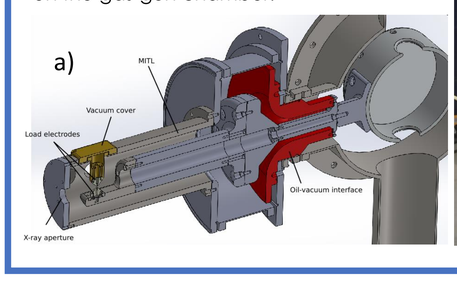


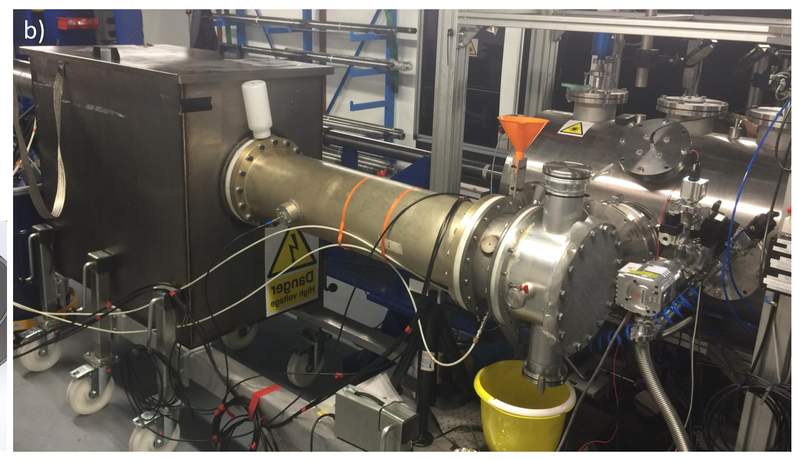
Fig. 1: Hytrac simulation (top) of planar impact of a polycarbonate projectile with a PMMA target. X-pinch radiograph (bottom) of equivalent experiment.

Pulsed-power

- 3-5 kJ Marx bank on loan from Imperial College London
- 4 Ω, 1 m PFL
- 70-100 kA in 70 ns
- Vacuum MITL delivers current to the x-pinch

Fig. 8: (a) Vacuum transmission line and load section. (b) X-pinch driver mounted on the gas-gun chamber.





X-pinch sources

- X-pinches are pulse-power driven point x-ray sources. A large pulsed current (>1 kA/ns) [2] is applied to an array of crossed fine wires that form an 'X' shape and a burst of x-rays is emitted:
  - Thermal plasma hotspot : **soft x-rays** (< 5 keV, <10 μm, 1 ns)
  - E-beam acceleration (non-thermal): **hard x-rays** (> 8 keV, 200 μm, >10 ns)
- We require 8-15 keV x-rays to probe through cm-scale targets, therefore we use the hard x-ray source.

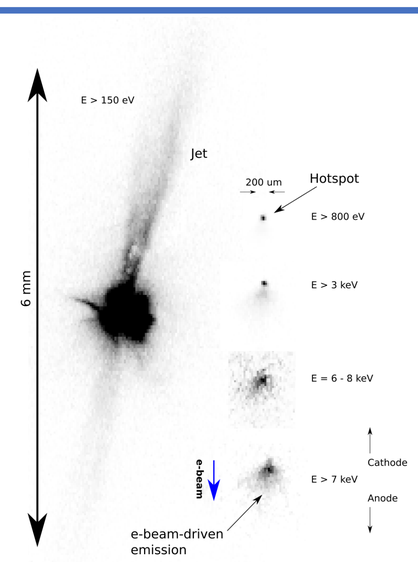


Fig.2: Time-integrated pinhole images of a 4 x 7.5 μm tungsten (W) X-pinch in different spectral bands.

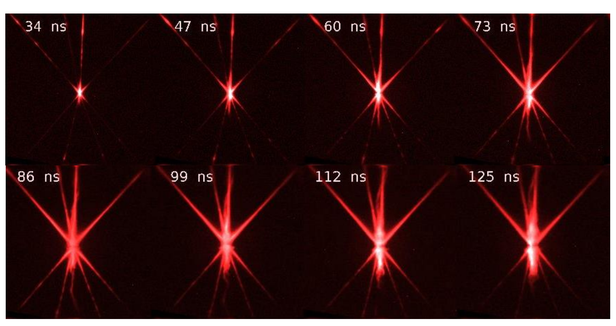


Fig.3: Optical emission sequence from a 4 x 7.5 μm tungsten X-pinch.

Source characterisation

- The source has been characterised using a number of techniques:
  - Differentially filtered, time-integrated pinhole and slit cameras provide information on source structure in different spectral bands.
  - Gated optical imaging shows the global evolution of the wire array.
  - Backlighting of fine grids to determine source size.
  - Crystal spectrometer for detailed spectral information.
  - Si x-ray diodes for temporal output.

Source Size: 300 μm
Energy Range: Up to ~20 keV
Yield: 20-50 mJ, > 8 keV
Duration: 20 ns

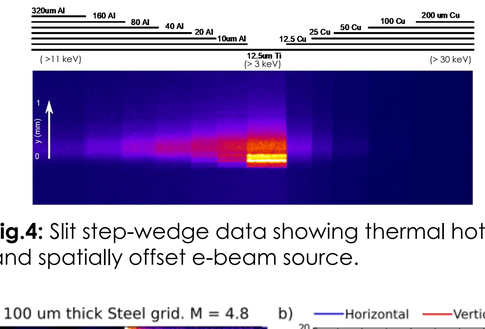


Fig.4: Slit step-wedge data showing thermal hotspot and spatially offset e-beam source.

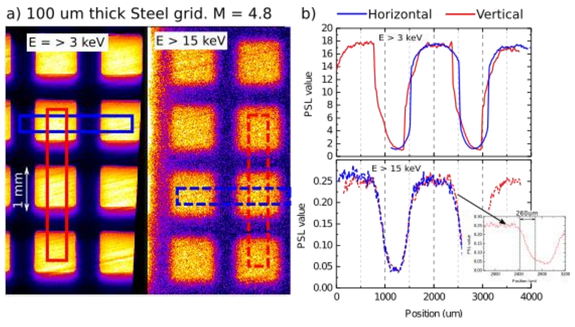


Fig.5: Point projection radiography of a steel grid through 12.5 um Ti (3 keV) and 1 mm Al (15 keV). Edge roll-off is used to determine source size (300 um) in orthogonal directions.

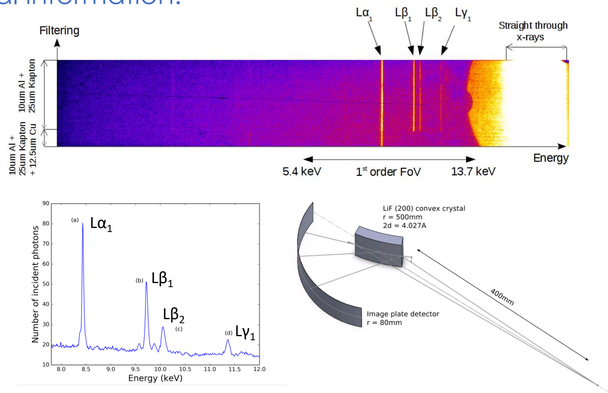


Fig.6: Temporally and spatially integrated spectrum from a tungsten X-pinch. Spectrometer from CEA.

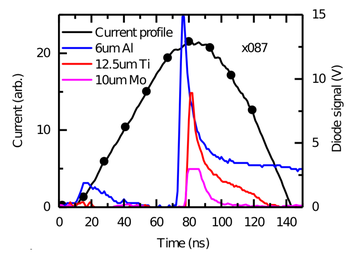


Fig.7: X-pinch current profile and typical signals on filtered Si x-ray diodes

Dynamic Imaging

- Radiography of an impact experiment driven by a two-stage light gas gun has been undertaken for the first time using an X-pinch x-ray source.

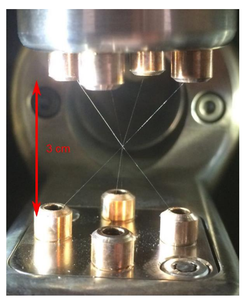


Fig. 9: Photograph showing a standard 4-wire 7.5μm Tungsten X-pinch

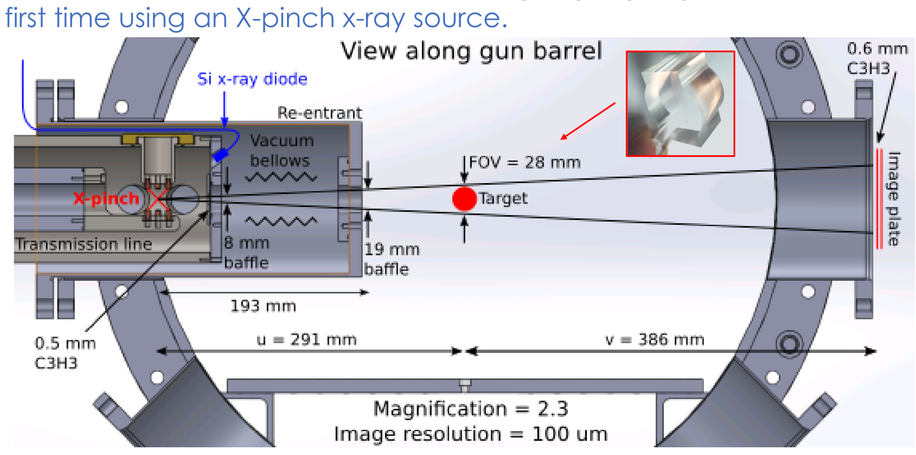


Fig. 10: X-ray backlighter within the gas gun target chamber.

- 15 mm diameter solid PMMA targets were impacted by 12.7 mm diameter polycarbonate projectiles at 6 km/s.
- Orthogonal optical and x-ray backlighting was performed.
- The internal forward and reverse shock structure are seen clearly in the x-ray data and only the shadow of the shock can be seen in the optical.

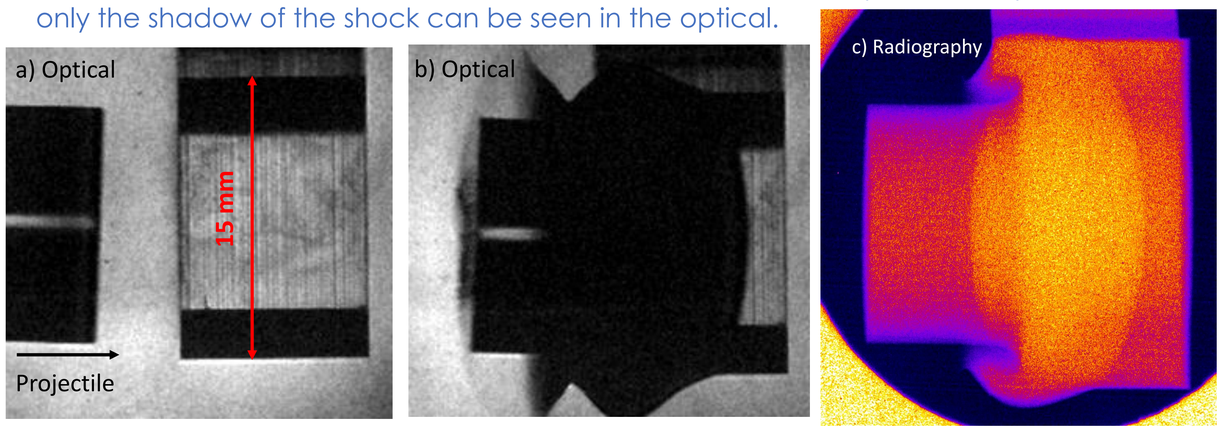


Fig. 11: Orthogonal optical (a-b) and x-ray backlighting (c) images from a 6 km/s polycarbonate projectile impact with a PMMA target. (a) Approaching projectile. (b) and (c) During impact.

Current and future work

- Shock release experiments for EoS measurements (poster by P. Allan on Monday)

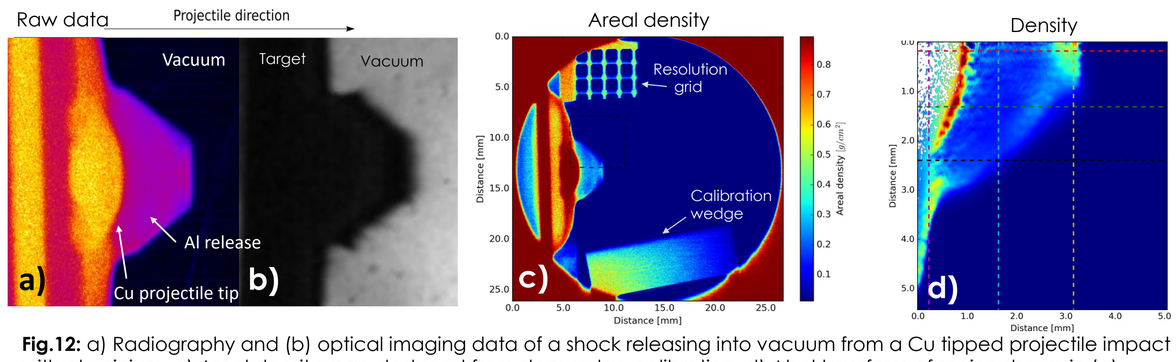
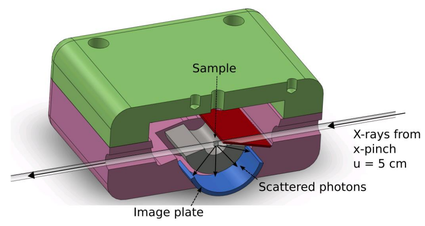


Fig.12: a) Radiography and (b) optical imaging data of a shock releasing into vacuum from a Cu tipped projectile impact with aluminium. c) Areal density map deduced from stepwedge calibration. d) Abel transform of region shown in (a) revealing the density structure of the release material.

- X-ray Thomson scattering experiments
  - Zucchini *et al*. [3] have previously demonstrated ability of a Mo x-pinch to produce Laue diffraction patterns at 17 keV.
  - We plan proof-of-principle offline scattering experiments at 8.5 keV with a W X-pinch.



References

1. Ringrose et al. Procedia. Eng. 204 (2017) 2. Pikuz, PPR 41, 4 (2015) 3. Zucchini *et al*. Rev. Sci. Instr. 86 (2015)