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Centre of Excellence in High Energy Plasma Physics

Imperial College London

Investigation of the interaction pulse in nested wire array z-pinches

D.J. Ampleford, C.A. Jennings, M.E. Cuneo, C. Deeney*

Sandia National Laboratories, Albuquerque, New Mexico, 87185-1106, USA

S.N. Bland, S.V. Lebedev, S.C. Bott, G.N. Hall, F. Suzuki, J.P. Chittenden

The Blackett Laboratory, Imperial College, London SW7 2BW, UK

*Present address: National Nuclear Security Administration, U.S. Department of Energy, Washington, DC 20585

National Nuclear Security Administration

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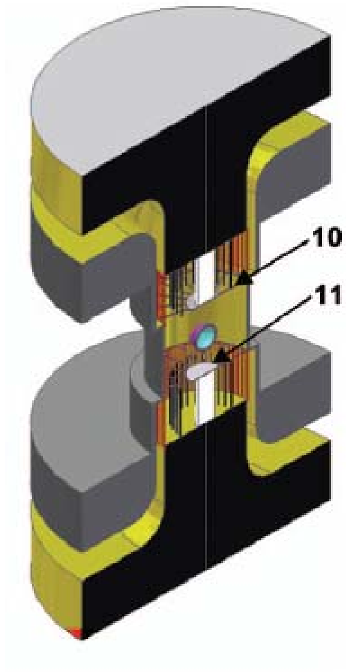
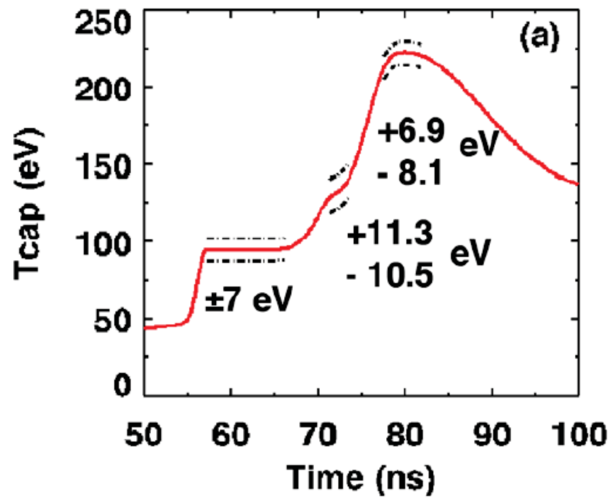
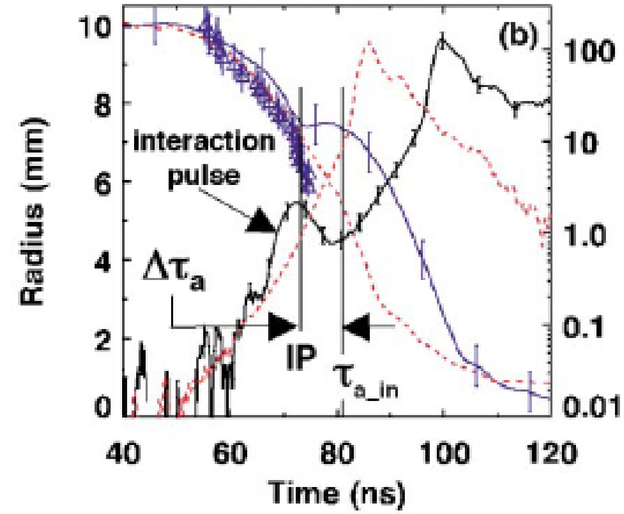
The interaction pulse in a nested array is vital to z-pinch ICF concepts







- Three or more controlled x-ray pulses are required in order to heat a fusion capsule
- One suitable pre-pulse is observed as the imploding outer array of two nested arrays interacts with the inner array
- This interaction on Z exceeds the power of snowplow emission from a single array by a factor of 2-3
- Z experiments indicate the power emitted by this interaction is independent of the number of wires and mass in the inner array
- Detailed physical mechanism of the interaction pulse is not fully understood

Images reproduced from
M.E. Cuneo et al. Phys Plas 13 056318, 2006

Nested wire arrays on MAGPIE use high inductance inner to suppress current through the inner array

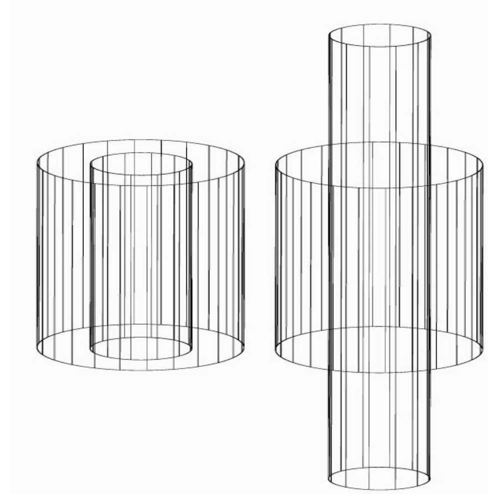
- High wire number in outer at 20MA leads to outer inductance >> inner inductance

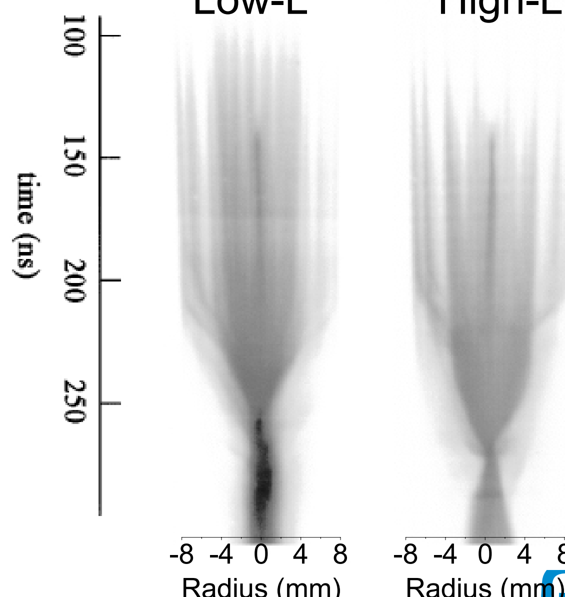
  e.g. Cuneo et al PRL 94, 225003 (2005)

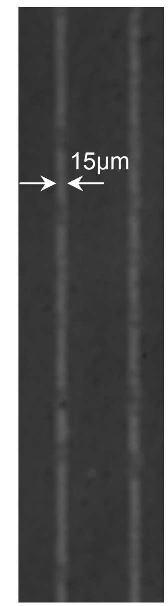
- High wire number not possible at ~1MA
- Array design can give same inductive division (by lengthening inner)

  Lebedev et al. PRL 84, 1708 (2000)

- Negligible inner current confirmed by
  - Radial optical streak
  - X-pinch radiography
  - B-dot probes
- Present experiments use
  - Outer array 16-32 x 10μm Al 5056 at 16mm
  - Inner array 16 wire Al, W or CH at 8mm
- Streak shows increased optical emission from position of inner despite little/no current







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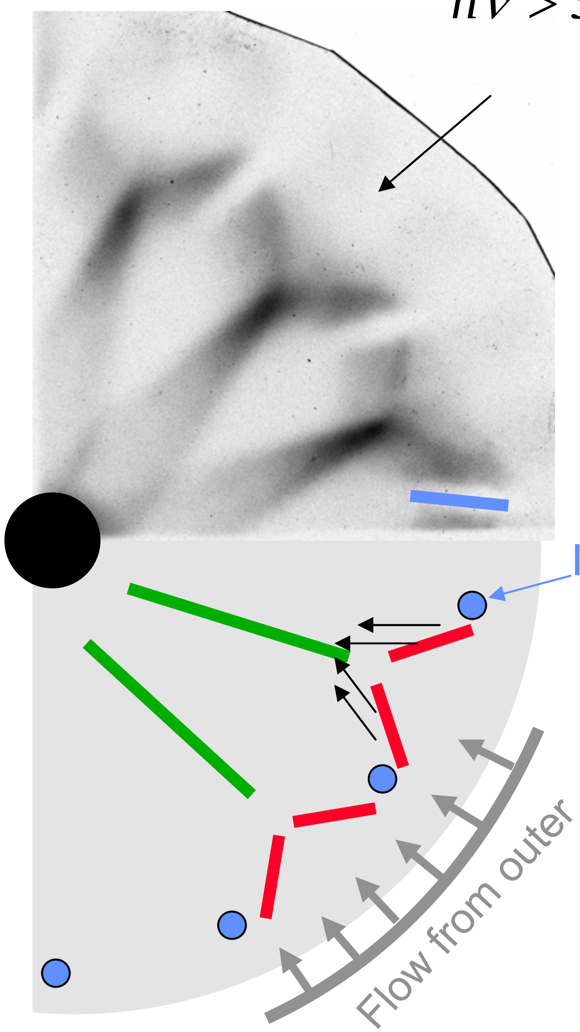
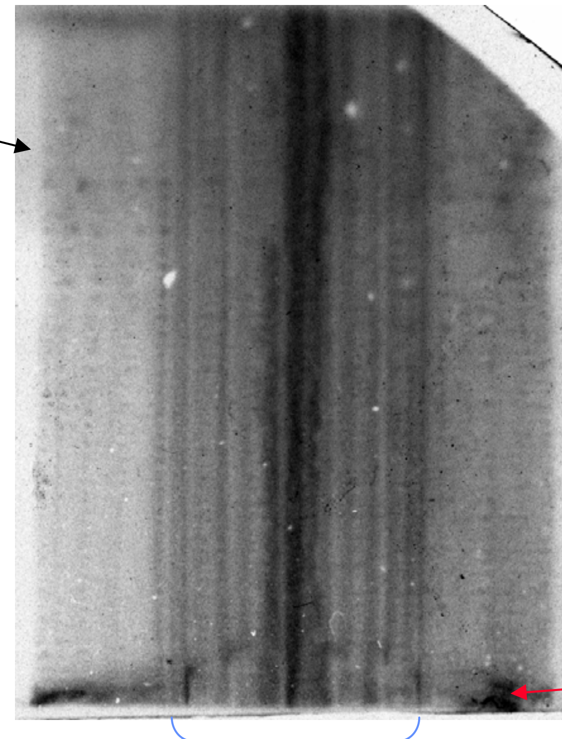
Structure of precursor streams passing inner gives indication of interaction dynamics

Al inner
~215ns
$h\nu > 30eV$





W inner, at 214ns

See poster GP1.00097 by C.A. Jennings et al.

M_{Al}~1.3, M_W~2.5

- Ablated streams perturbed by presence of inner forming bow shocks
- Shock leads to increased emission at position of inner (shock heating and change in density distribution)

Shock jump calculations

- Estimate jump conditions:

$$\frac{T_1}{T_0} = 1 + \frac{2(\gamma-1)}{(\gamma+1)^2}\frac{M_{\perp 0}^2 - 1}{M_{\perp 0}^2}\left[\gamma M_{\perp 0}^2 + 1\right]$$

$$\frac{\rho_1}{\rho_0} = \frac{(\gamma+1)M_{\perp 0}^2}{(\gamma-1)M_{\perp 0}^2 + 2}$$

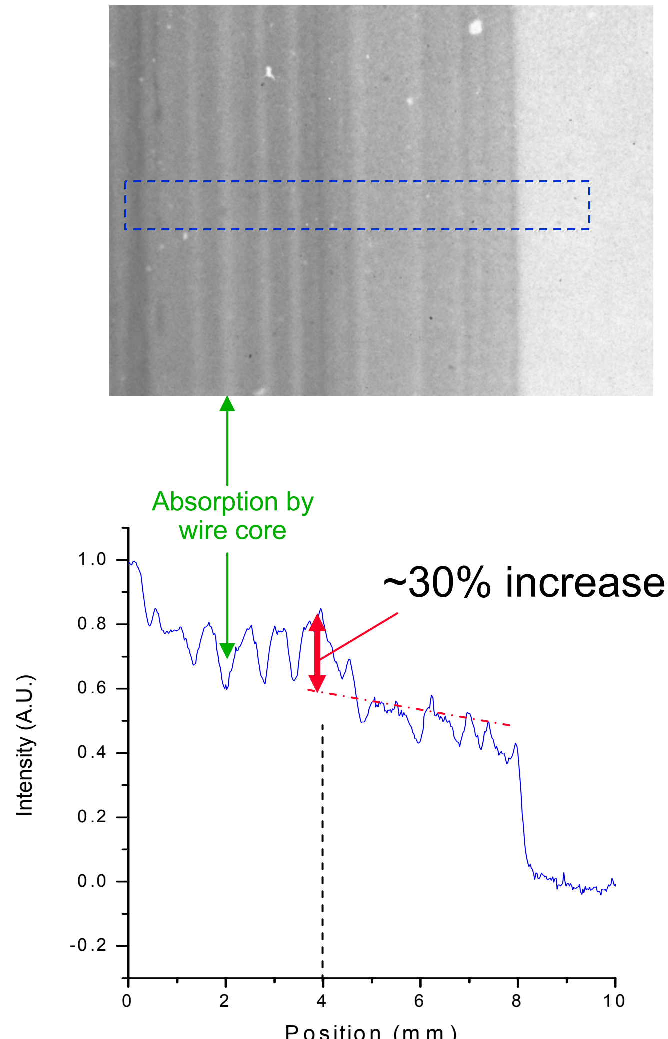
- For MAGPIE conditions estimate M~1.5, γ~1.3

- From these, can estimate change in emission from incoming flows, e.g. assuming recombination emission:

$$\frac{P_1}{P_0} = \frac{\rho_1^{\,2}/\sqrt{T_1}}{\rho_0^{\,2}/\sqrt{T_0}} \sim 1.3$$

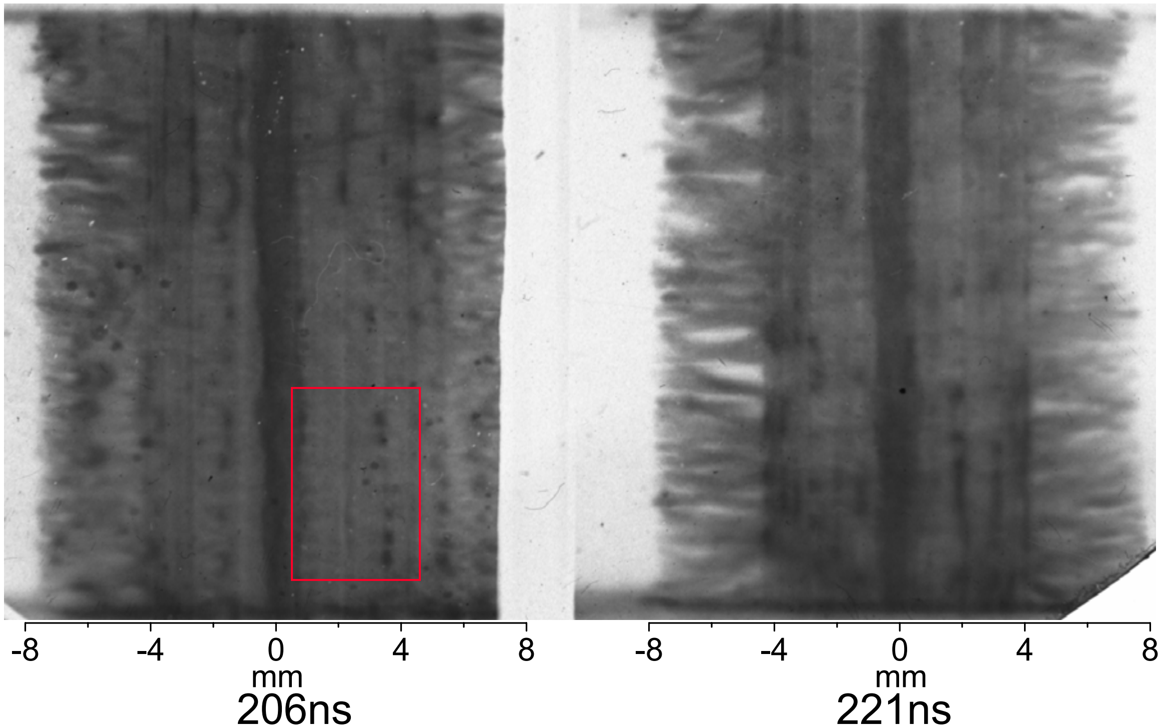
- Lineout of image is consistent

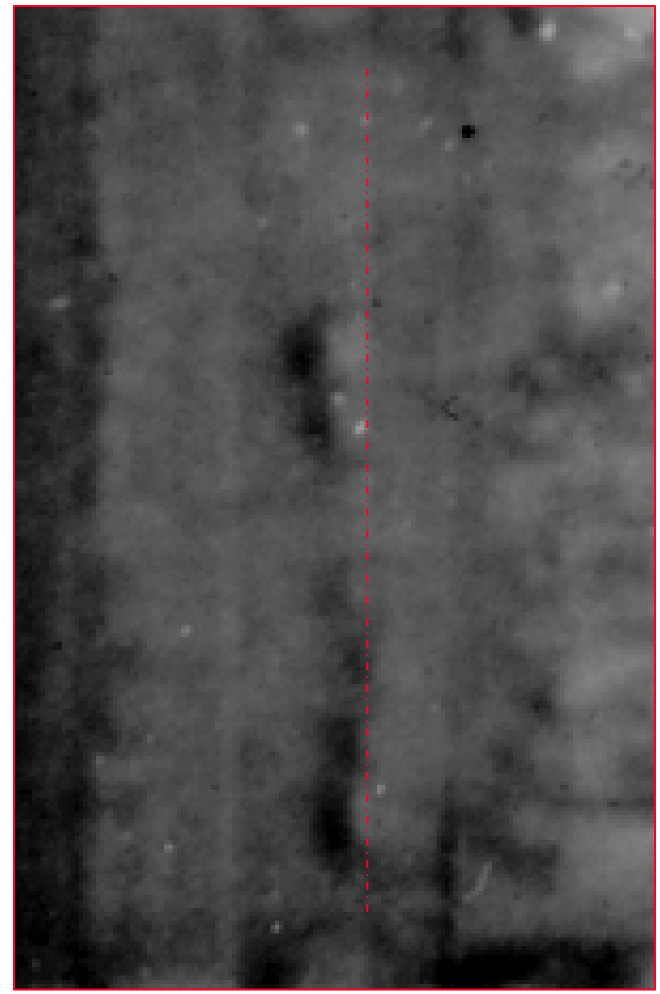
- Shock setup should be steady state before imploding outer reaches it



N.B. Approximate - no MCP/film correction

Interaction: Bubbles emit as they pass inner

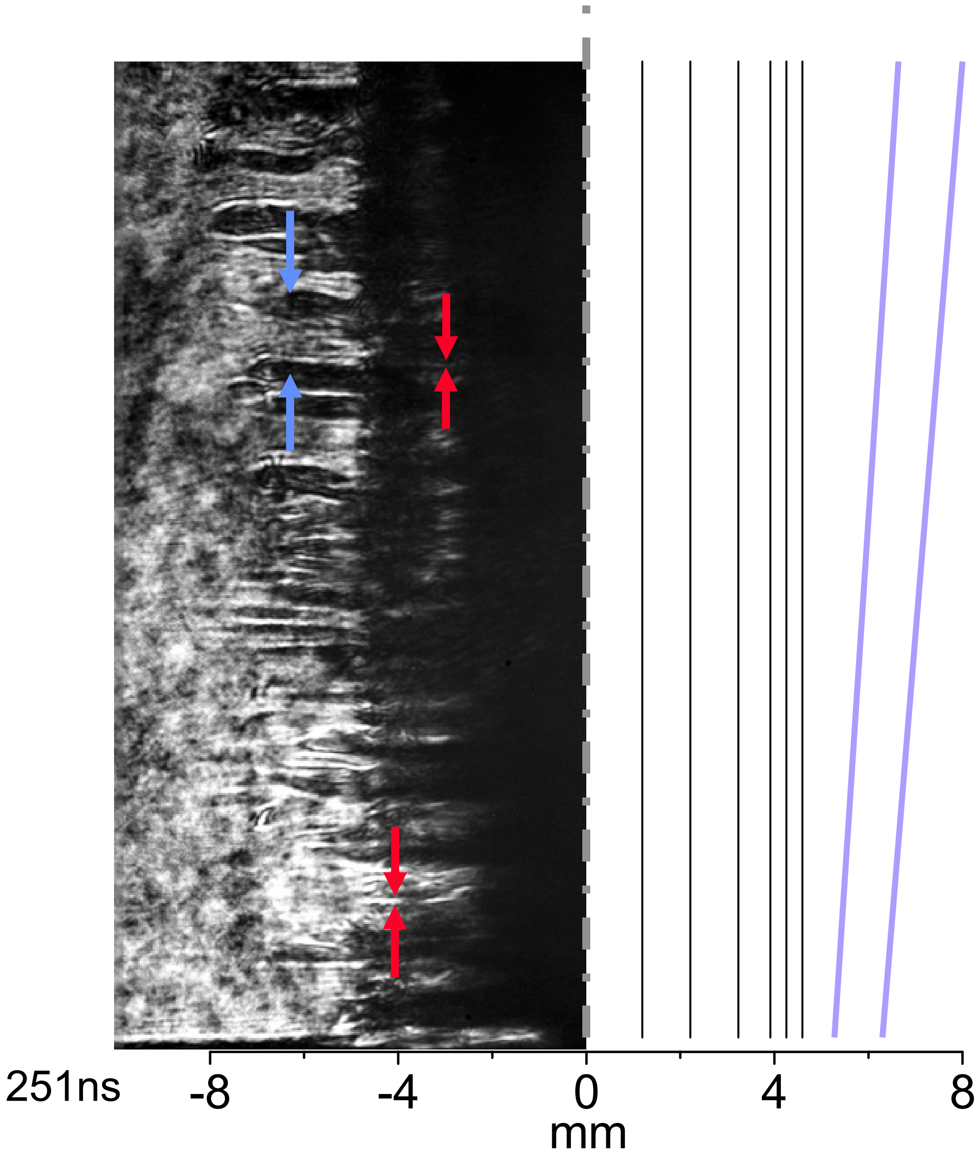




On MAGPIE see enhanced emission from imploding bubbles as they reach the inner array

Detailed image demonstrates this emission increases inside the inner wires

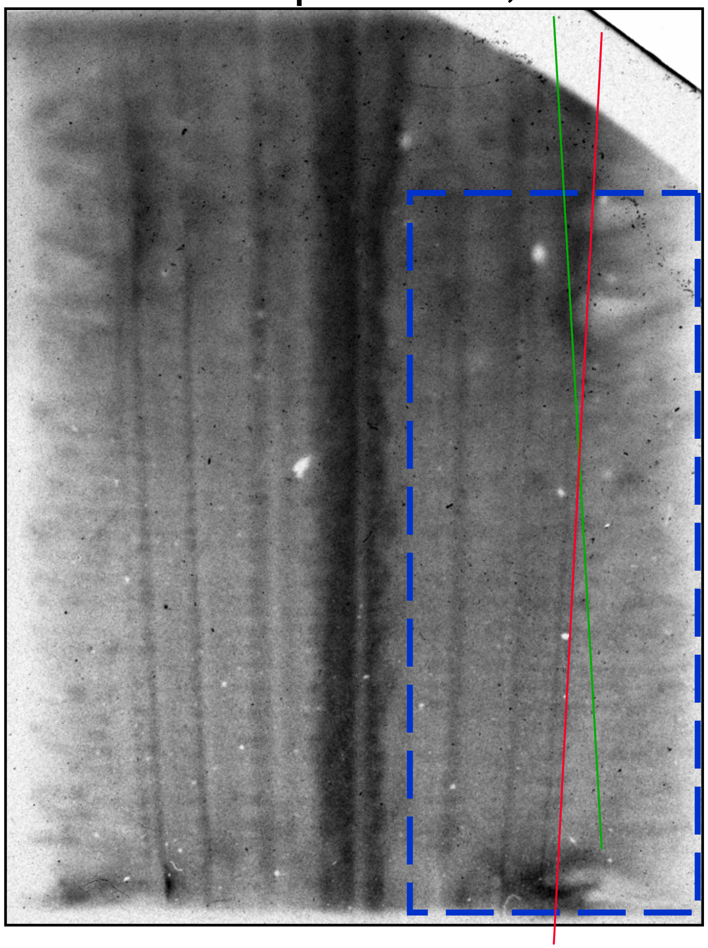
Interaction with inner resets implosion wavelength

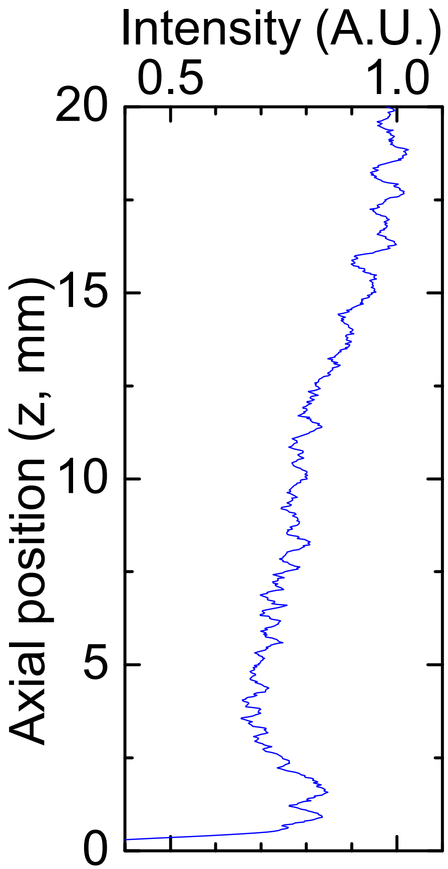


- Conical outer onto cylindrical inner shows change in wavelength is different before and after interaction with inner
- Interaction resets wavelength to sub-mm natural mode

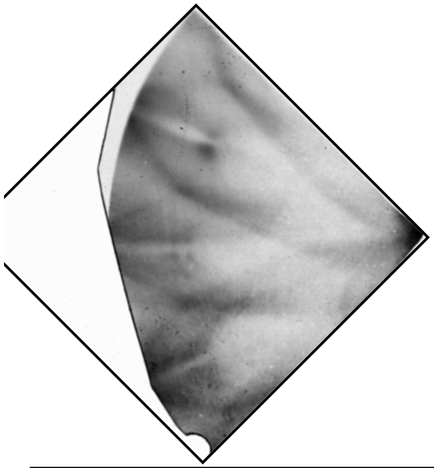
Conical inner isolates snowplow from interaction

- Setup designed such that snowplow is constant along axis, however interaction time changes
- See emission from bubbles interacting with inner near for larger inner radius positions, but not at smaller inner radius

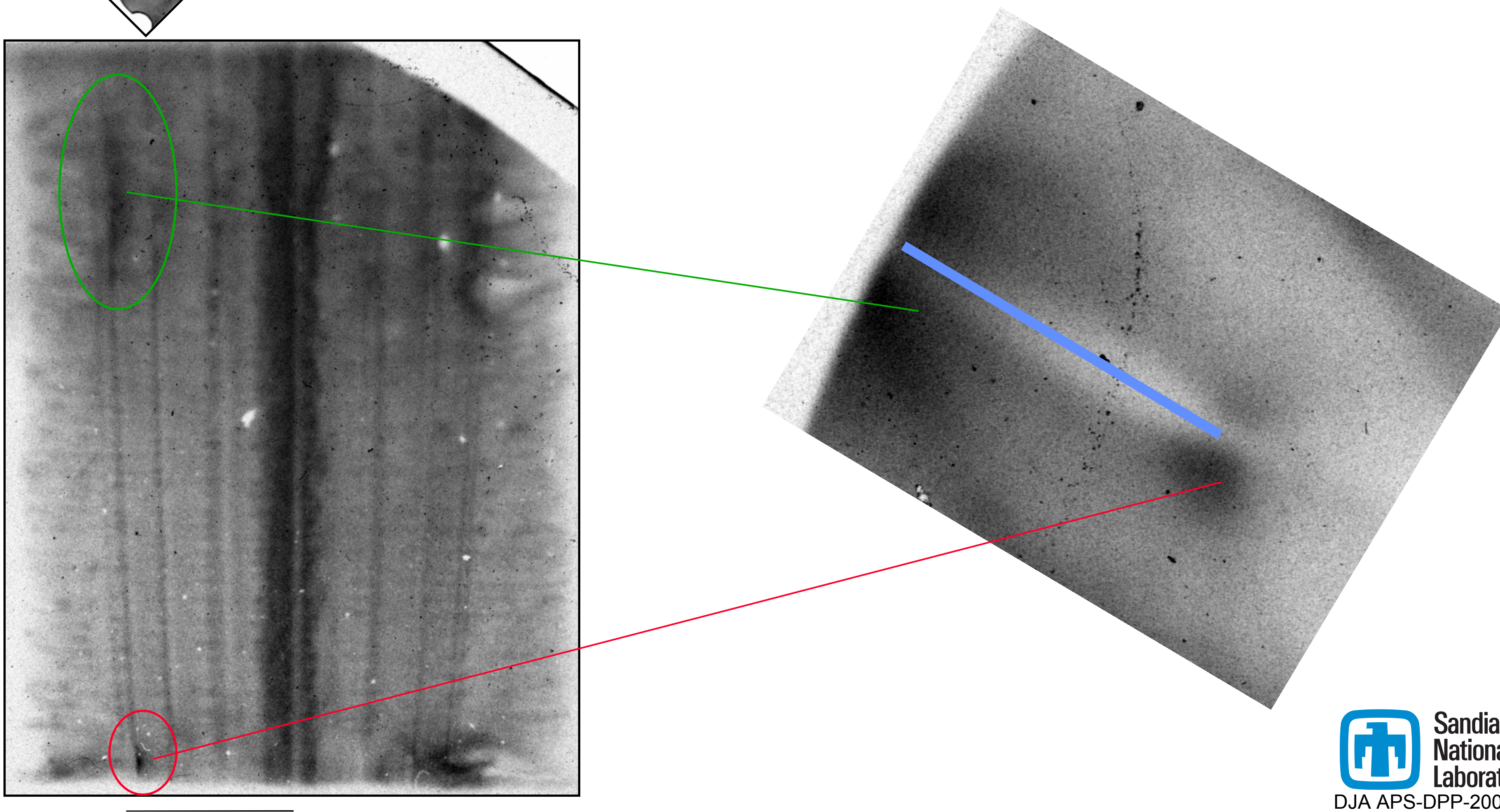




End-on probing shows interaction



- See interaction emission surrounds wire, possibly in bow-shock type structure



Perturbing the pre-fill will effect the snowplow

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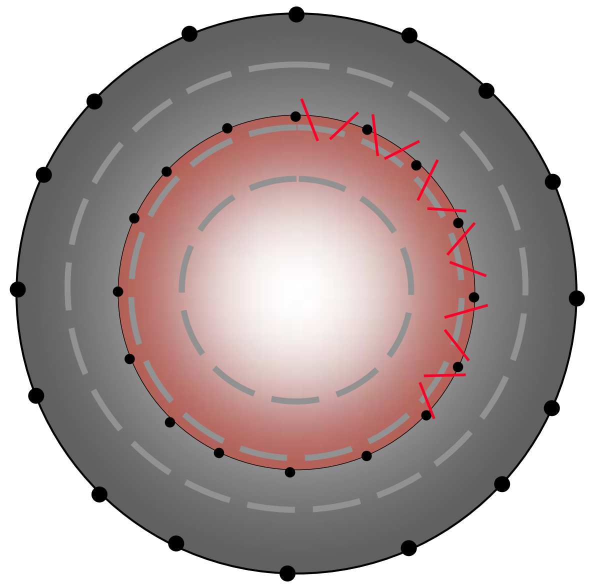
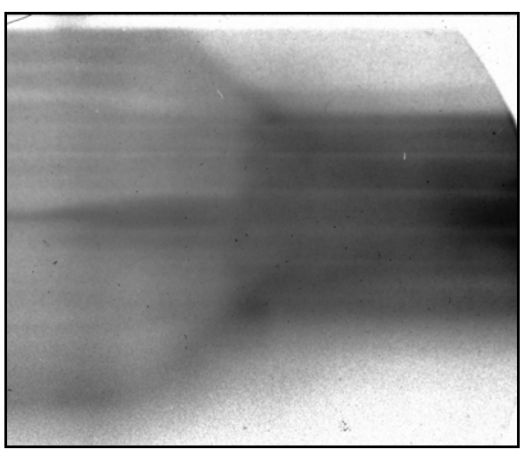
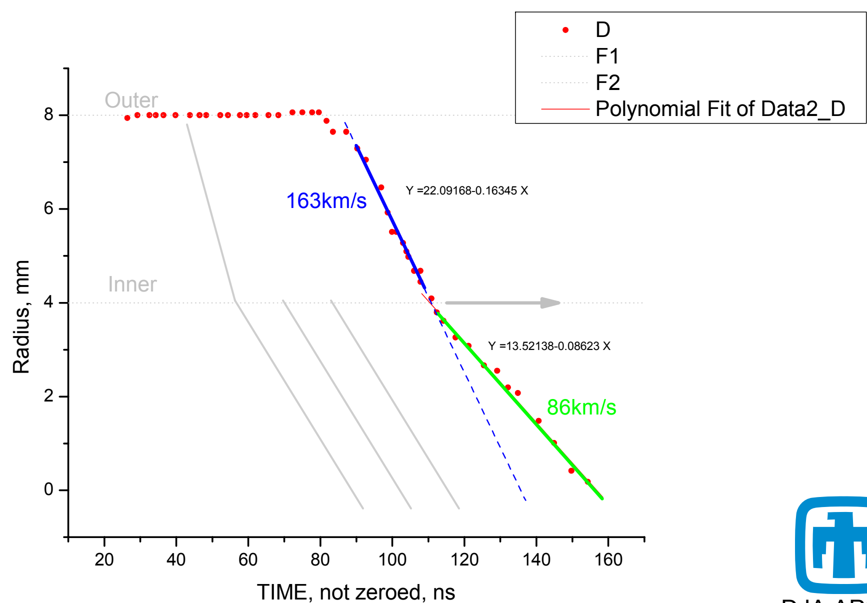
- For single array snowplow of prefill by implosion results in emission
- Power radiated by snowplow emission is
  - $P_{SP} \propto \rho(r,t)\,(v_{piston} - v_{prefill})^3$
- Compared with single, ρ and $v_{prefill}$ both altered, each acting to enhance snowplow emission.
- As piston accretes mass whilst losing current fraction to inner wires slows to the velocity of prefill material

  Jump conditions $\rightarrow v_1 \sim 77$km/s







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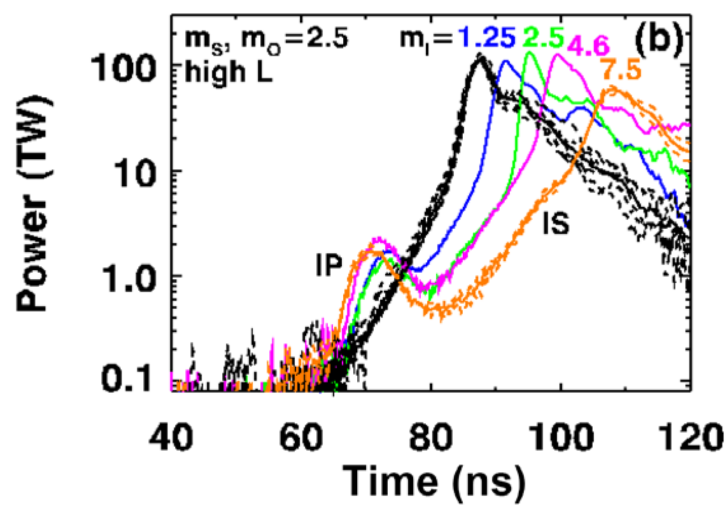
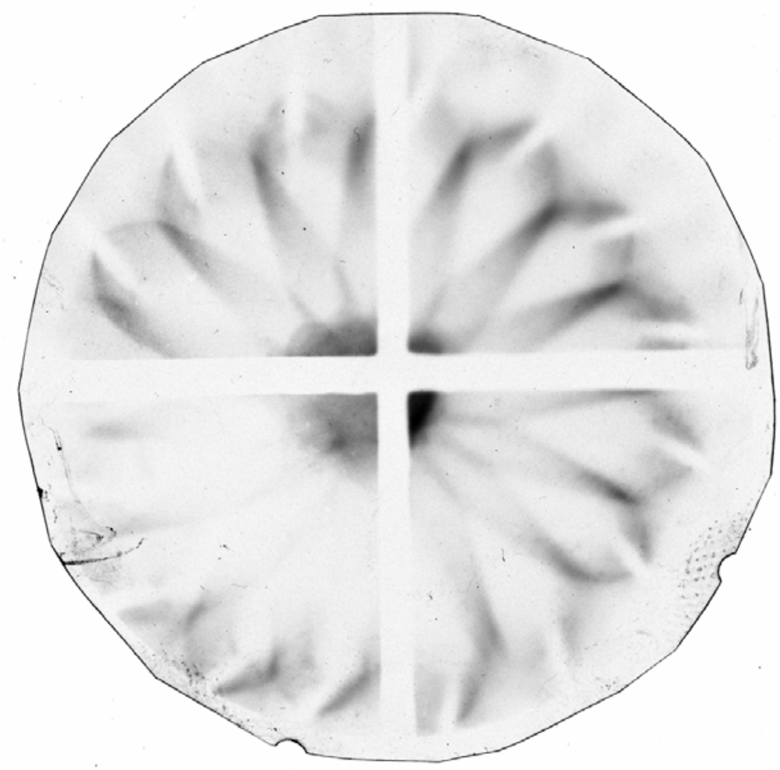
Shock structures are likely to have an effect on Z

- Ablation flows will have higher Mach number for W arrays on Z than Al on MAGPIE
- Higher wire number (>30) will lead to near-continuous shock around inner, so insensitive to inner wire number
- If shock is completely cylindrical expect 5 fold increase over single array snowplow
  - with $V_{abl} \sim 10$cm/µs, $V_{piston} \sim 22$cm/µs
- Structure will reduce this factor (e.g. bow shock curvature)
- Data indicates 2-3 fold increase



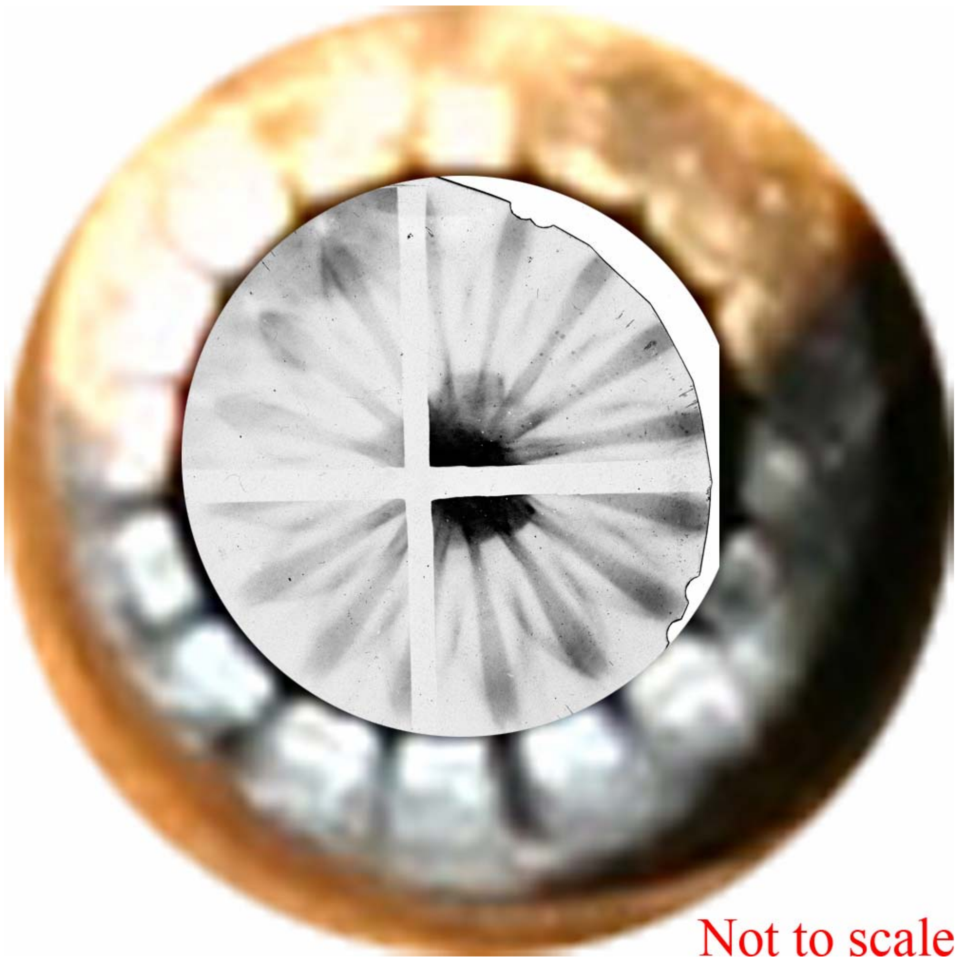
Summary

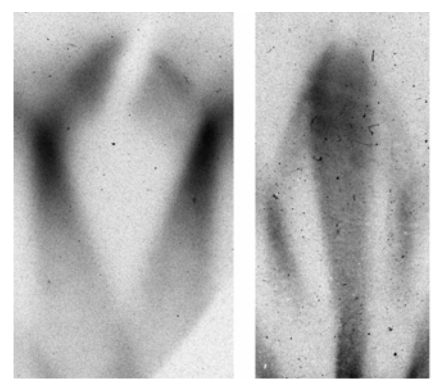
- Precursor plasma streams are shocked on MAGPIE
- Shock will alter ρ, T, v of the streams
- This jump is likely to alter the snowplow emission as the array implodes
- For Z conditions this change in snowplow radiation may be comparable to the observed interaction pulse



Backup

End-on orientation





32 wire single end-on and side-on