Investigations of Bow Shock Formation in Radiatively-cooled Supersonic Plasma Flows

PULSED POWER PLASMAS GROUP

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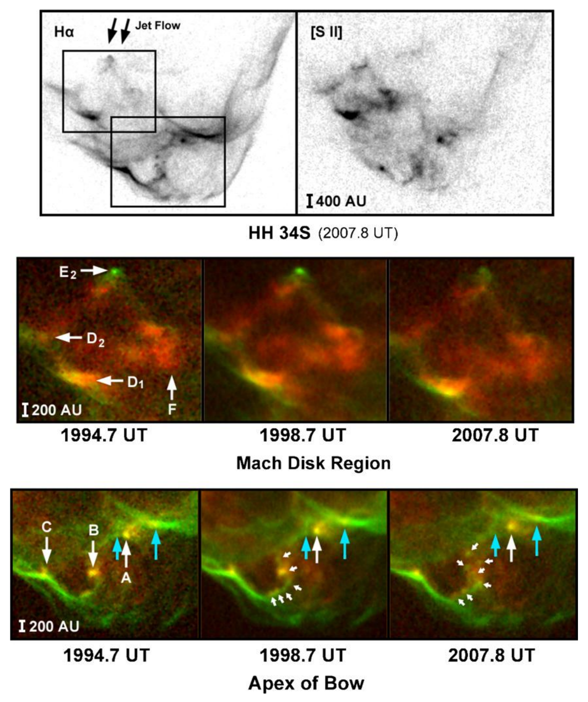
Introduction

This work is motivated by the need to better understand the role of strong radiative cooling in shock formation in plasma flows.

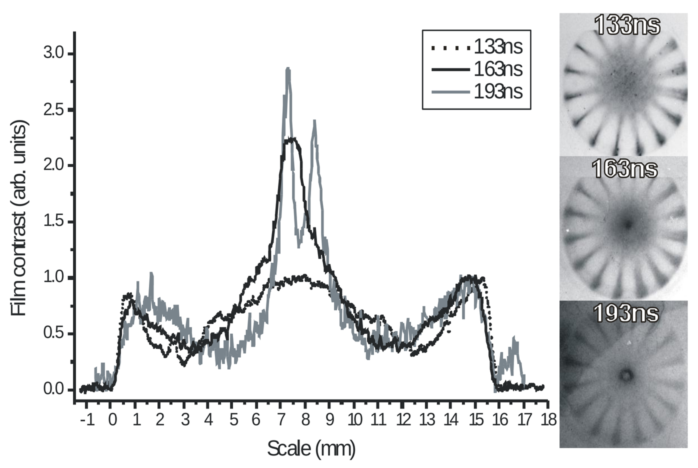
We are developing an experimental system to provide a means of analysis for bow shock formation in supersonic flows.

Relevant to many astrophysical systems, including propagation of YSO jets.

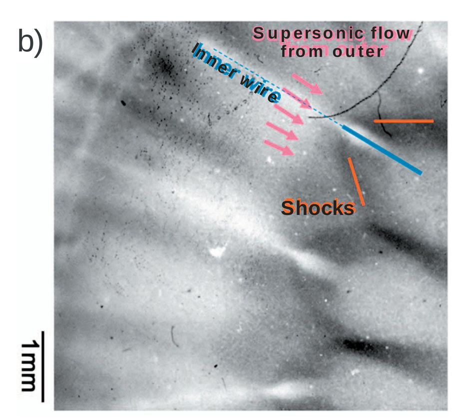
Pulsed power driven wire arrays readily produce high velocity flows in which radiation loss is important.



from Hartigan et al [1]



from Bott et al [2]



from Ampleford et al [3]

Experimental Design

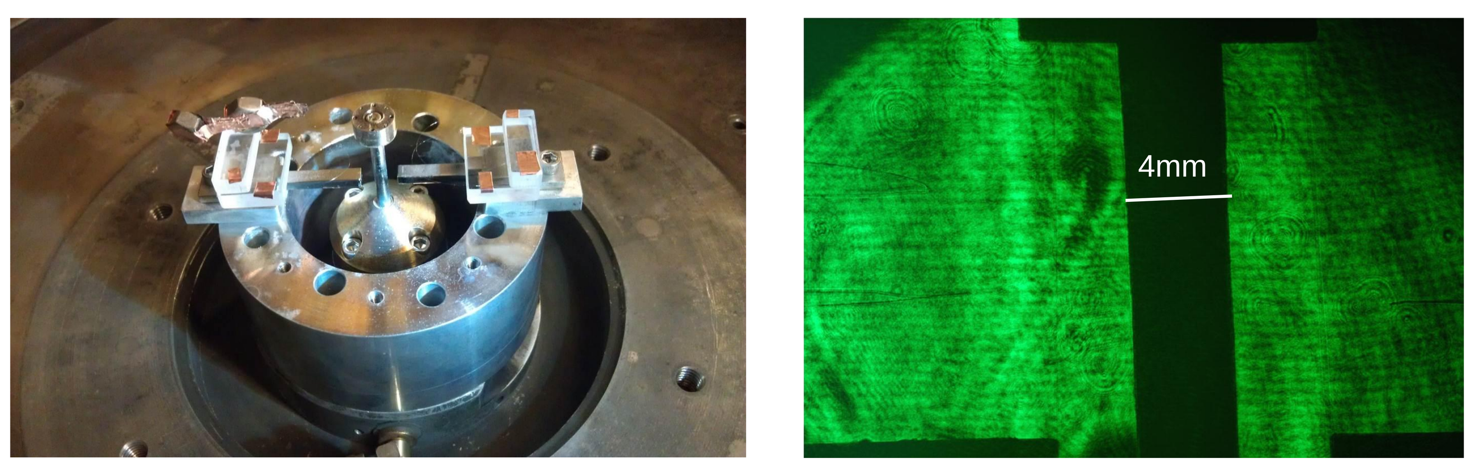


Figure 1: Photograph of the experimental setup, and laser shadow showing target alignment to load

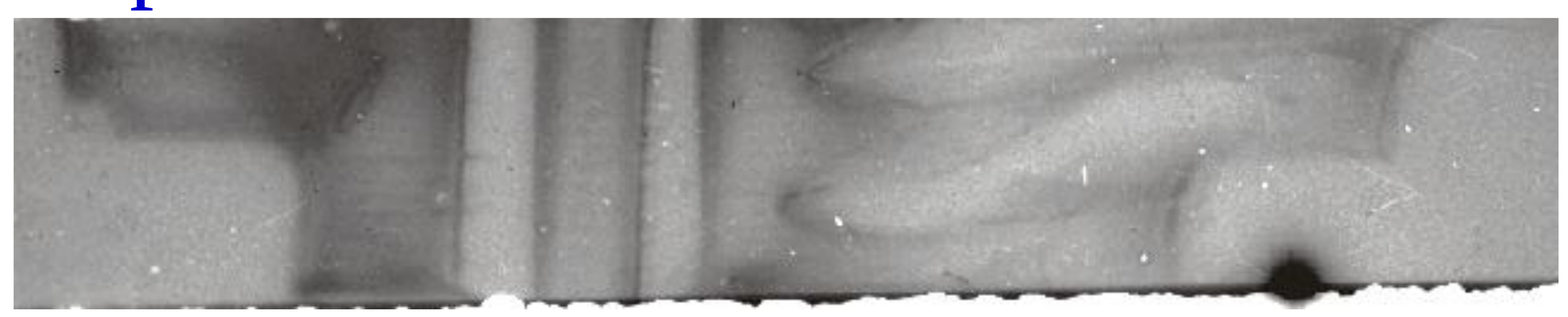
- Requirements for the upstream flow is that it is supersonic and uniform
- Exploding wire arrays readily generate JxB accelerated flows from metallic wires using currents of >100kA
- Velocities are typically ~100 km/s with temperatures of order 5-10eV

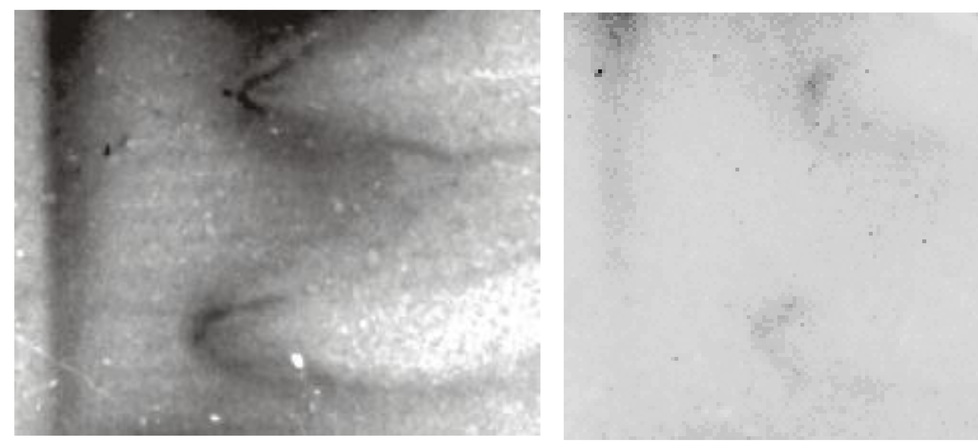
$$n_e L(r,t) = -\frac{\mu_0 Z}{4\pi V_{abl}^2 N_{wires} m_p}\left[I\left(t-\frac{r-R_0}{V_{abl}}\right)\right]^2$$

- The flow density can be estimated analytically [3] to ensure that the flow is collisional on the expected scale-length of the system (<0.5mm)

$$\lambda_{perp} = \frac{m_{ion}^2 v_{abl}^3}{8\pi Z^4 e^4 n_{ion} \ln\Lambda\sqrt{\pi/2}}$$

Experimental Results





$L_{geo} = 520\mu m$
$h\upsilon > 10eV$

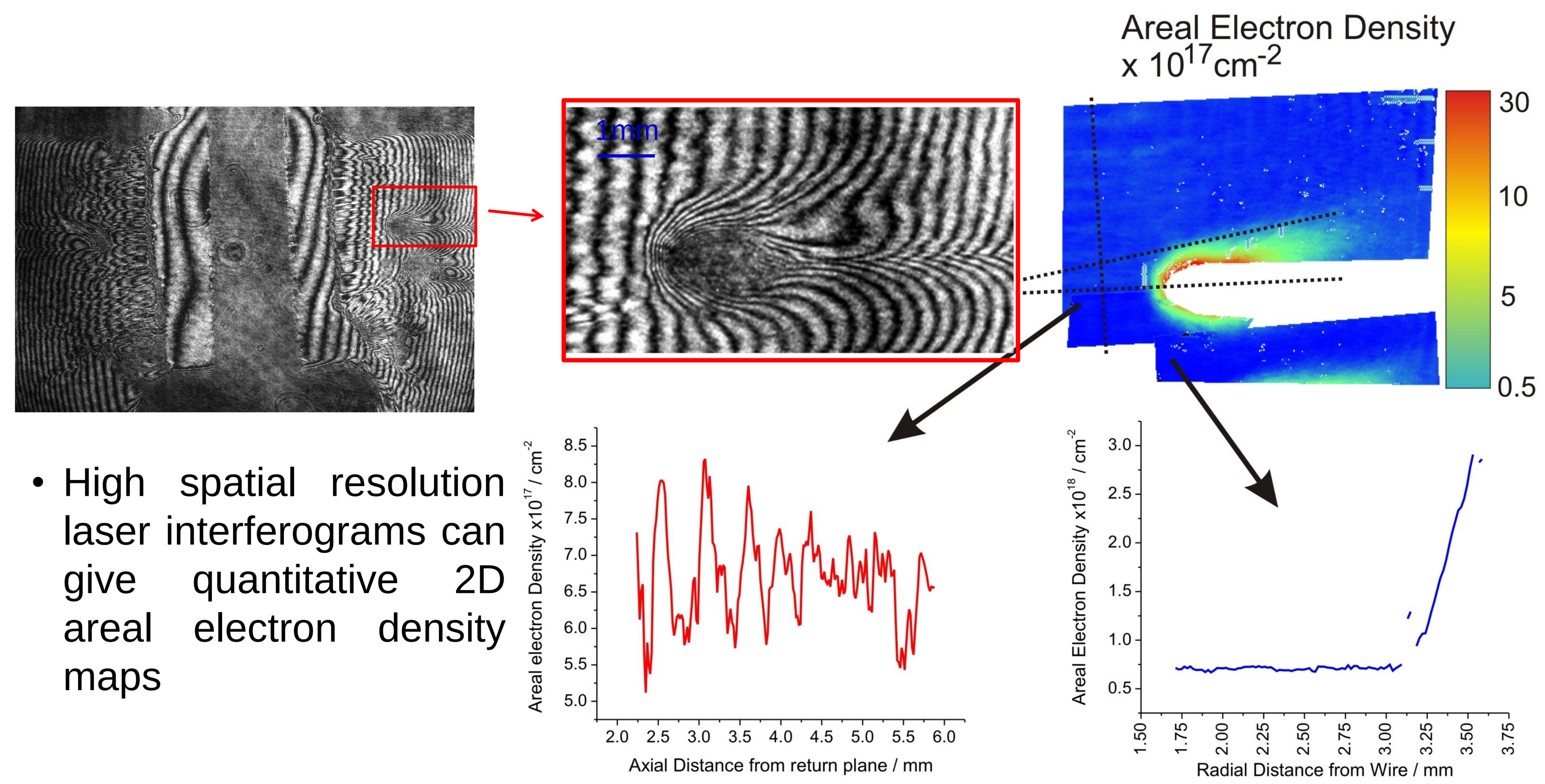
$L_{geo} = 130\mu m$
$h\upsilon > 160eV$

Approximate shock temperatures can be recovered from XUV images

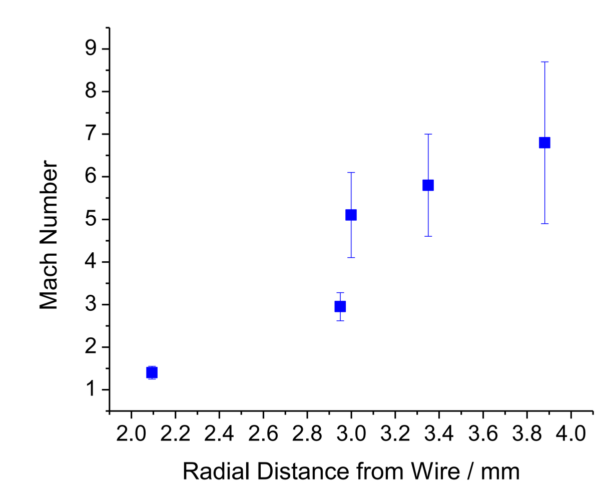
$$L_{geometric} = l\left(1+\frac{1}{M}\right)$$

$$L_{diffraction} = 1.22\frac{\lambda p}{d}$$

- Temperature at the impact region are of order 40 eV with rapid cooling to ~few eV behind the shock

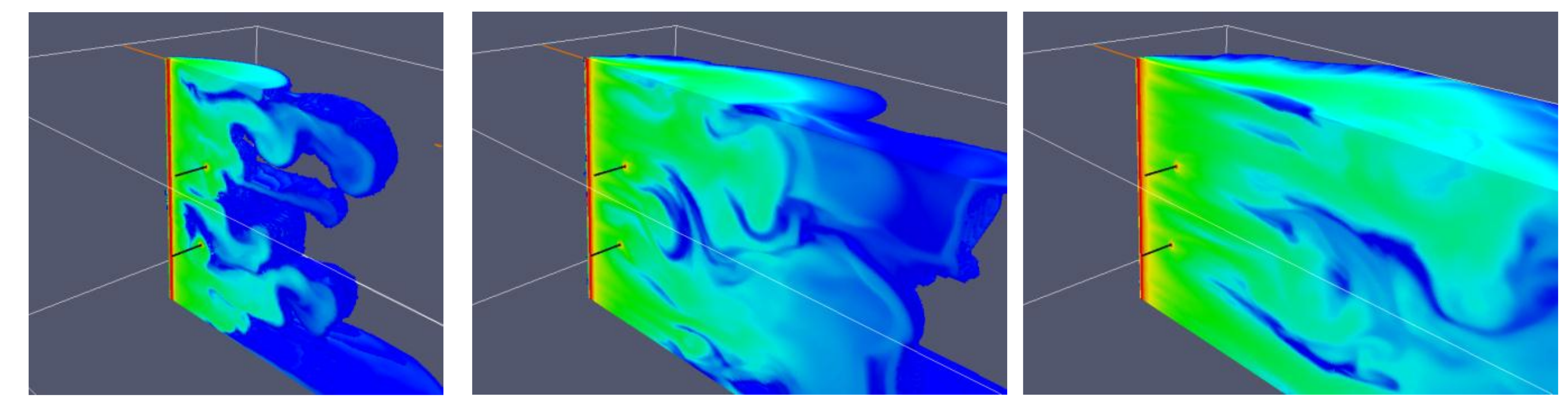


- High spatial resolution laser interferograms can give quantitative 2D areal electron density maps
- High compressibility means shock regions is too dense for laser to penetrate at late times
- Upstream flow is quasi-uniform, and axial variation is <10%
- Shock angle decreases with radial position
- If flow velocity is approximately constant, flow is cooling strongly

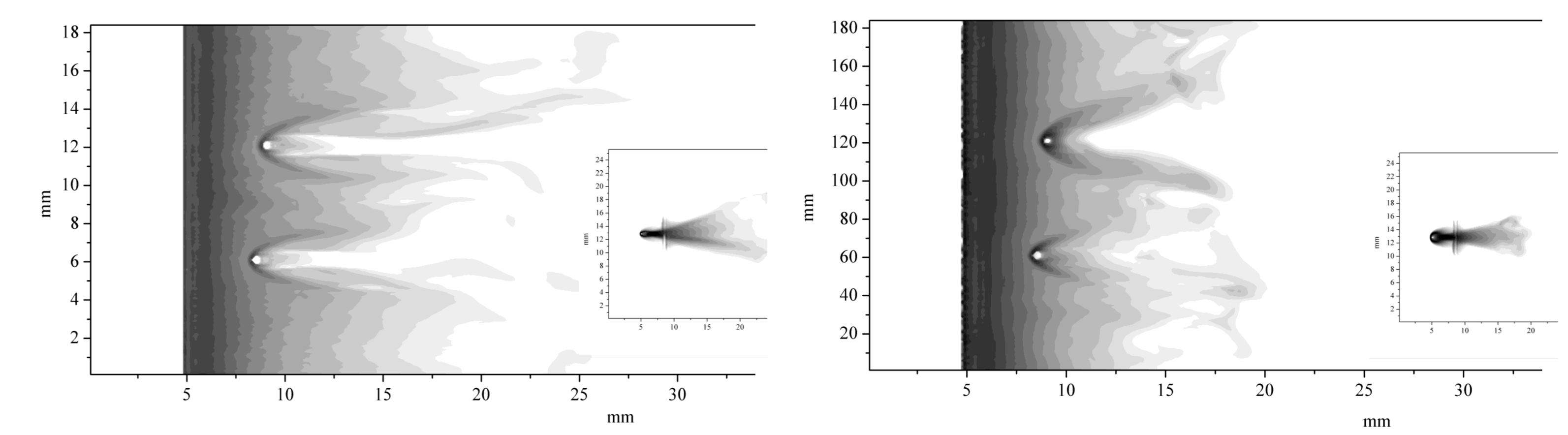


MHD Simulations

Simulation work was carried out at Imperial College London using the 3D MHD code GORGON [3]



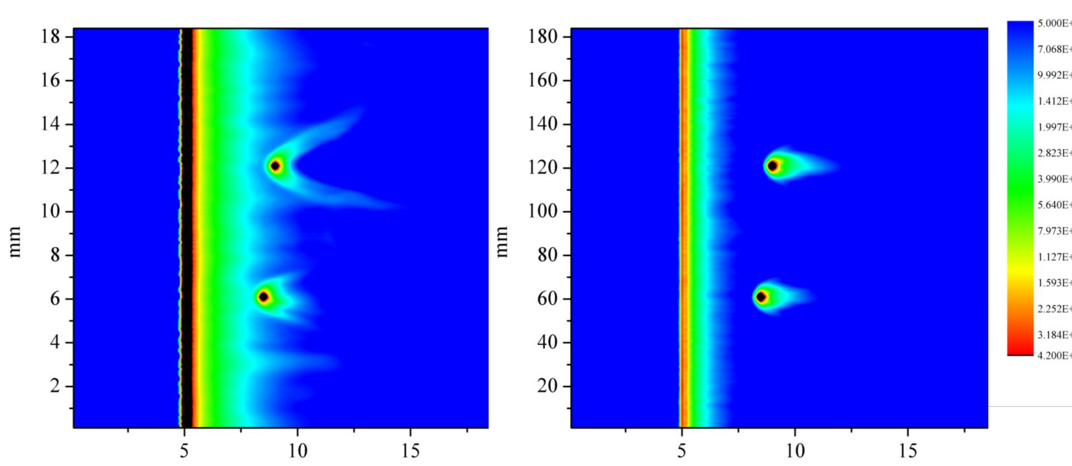
Plots show color coded mass density contours from a 3D simulation (100μm cell size over 20 x 20 x 30 mm domain) showing plasma streams from the ablating wire impacting the target wires.



Direct comparisons are made to the experiment by integrating emission and electron density to produce synthetic X-ray images and interferometry.

Clear differences are observed by changing the flow cooling rate (material)

Trends are similar to experiments but some differences in the detailed shock structure



Conclusions

- Bows shock studies using inverse wires array look to be a promising tool
- Need detailed comparison for different material (cooling and ionization rates), and to examine effect of LTE vs non-LTE ionization routines
- More studies planned in different geometries to more fully understand the details of the radiative loss rate in these systems
- Future work will also examine the role of collisionality in shock formation in these systems, and it is relatively simple to add B-fields of several Tesla

References

[1] P. Hartigan *et al*, *Ap.J.* **736**, 29 (2011)
[2] S. C. Bott *et al*, *Phys. Rev. E*, **74**, 046403 (2006)
[3] D. J. Ampleford *et al*, *Phys. Plasmas*, **17**, 056315 (2010)
[4] A. J. Harvey-Thompson *et al*, *Phys. Plasmas*, **16**, 022701 (2009)
[5] J. P. Chittenden *et al*, *Plasma Phys. Control. Fusion*, **46**, B457, (2004)

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