Investigation of Magnetized, Radiative Bow-Shocks in Magnetically Accelerated Plasma Flows

PULSED POWER PLASMAS GROUP

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JetPAC

Jets: A Plasma and Astrophysics Collaboration

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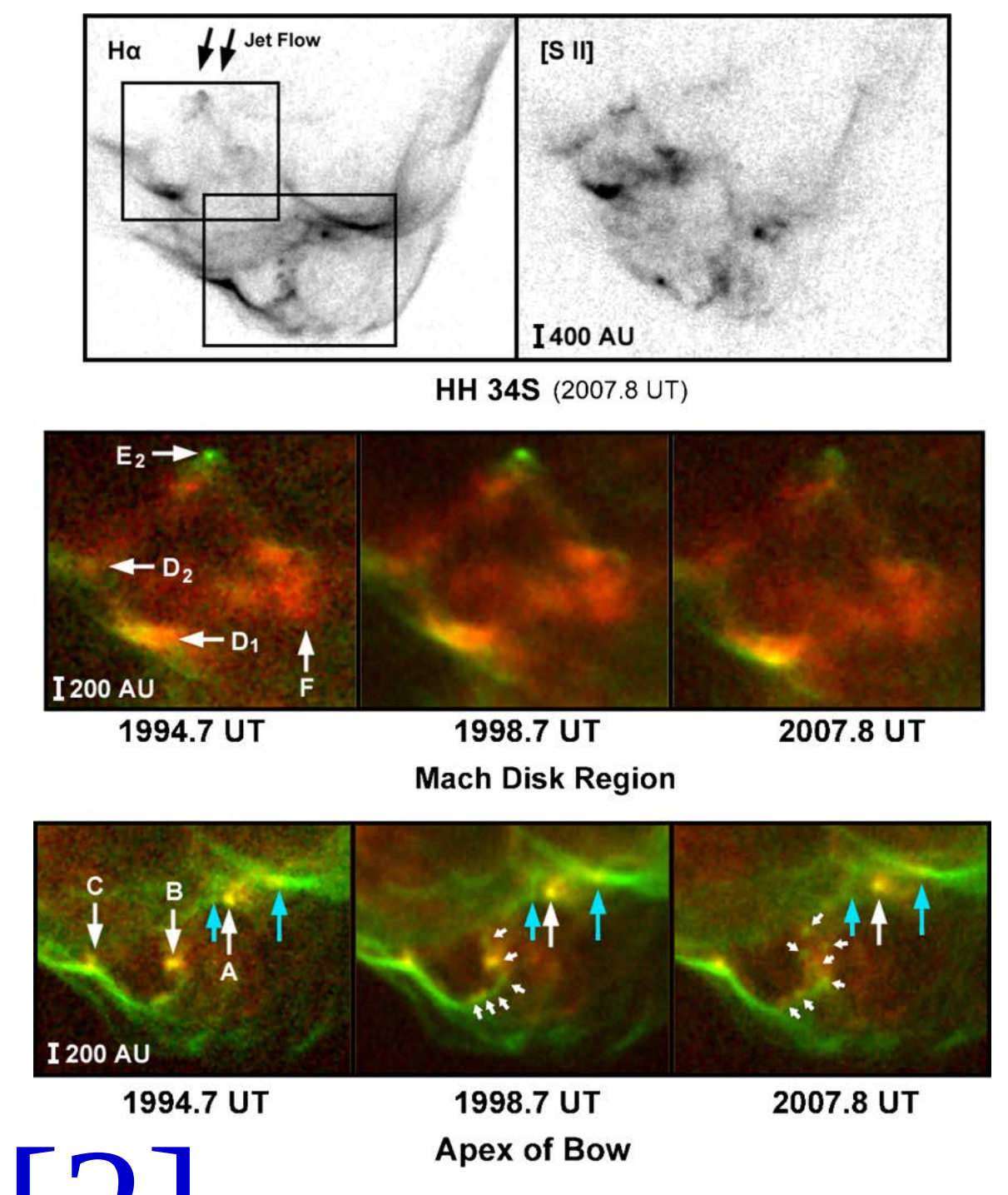
Introduction

- 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 systems are excellent for producing long lived flows, 'large scale' flows and large magnetic fields



Hydrodynamic Shocks [2]

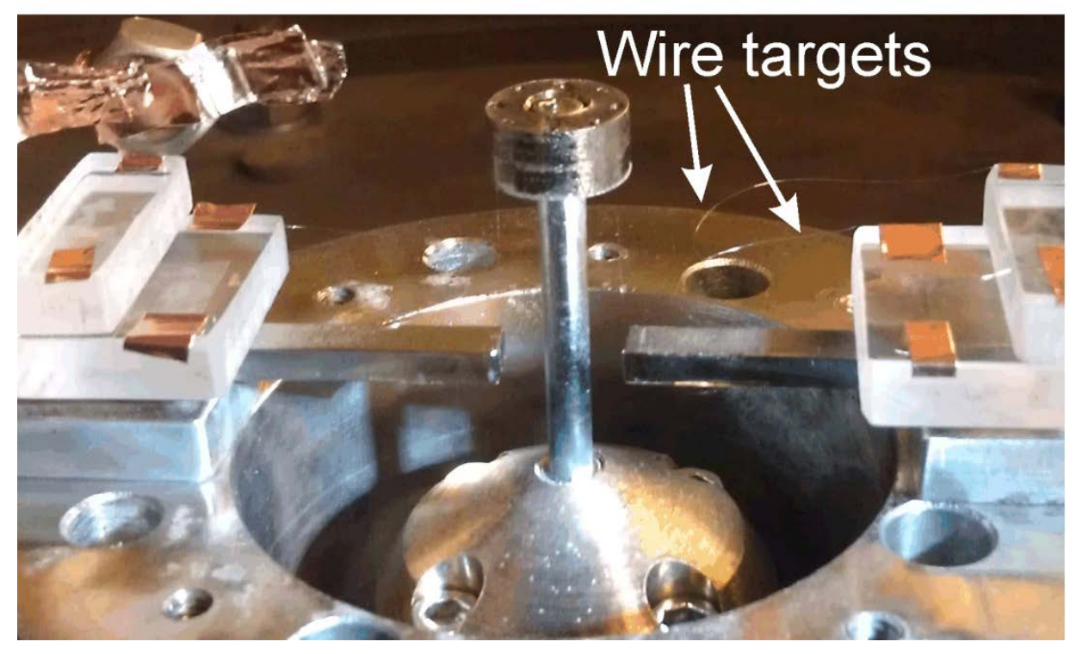
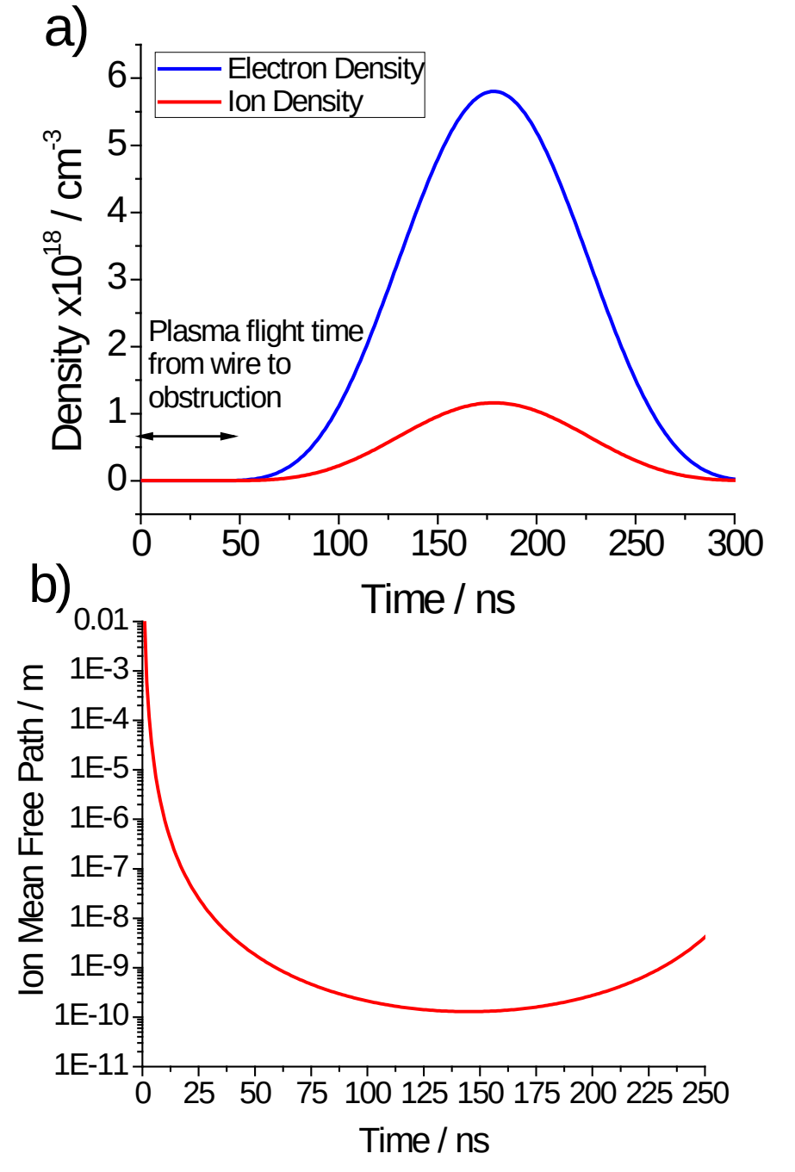


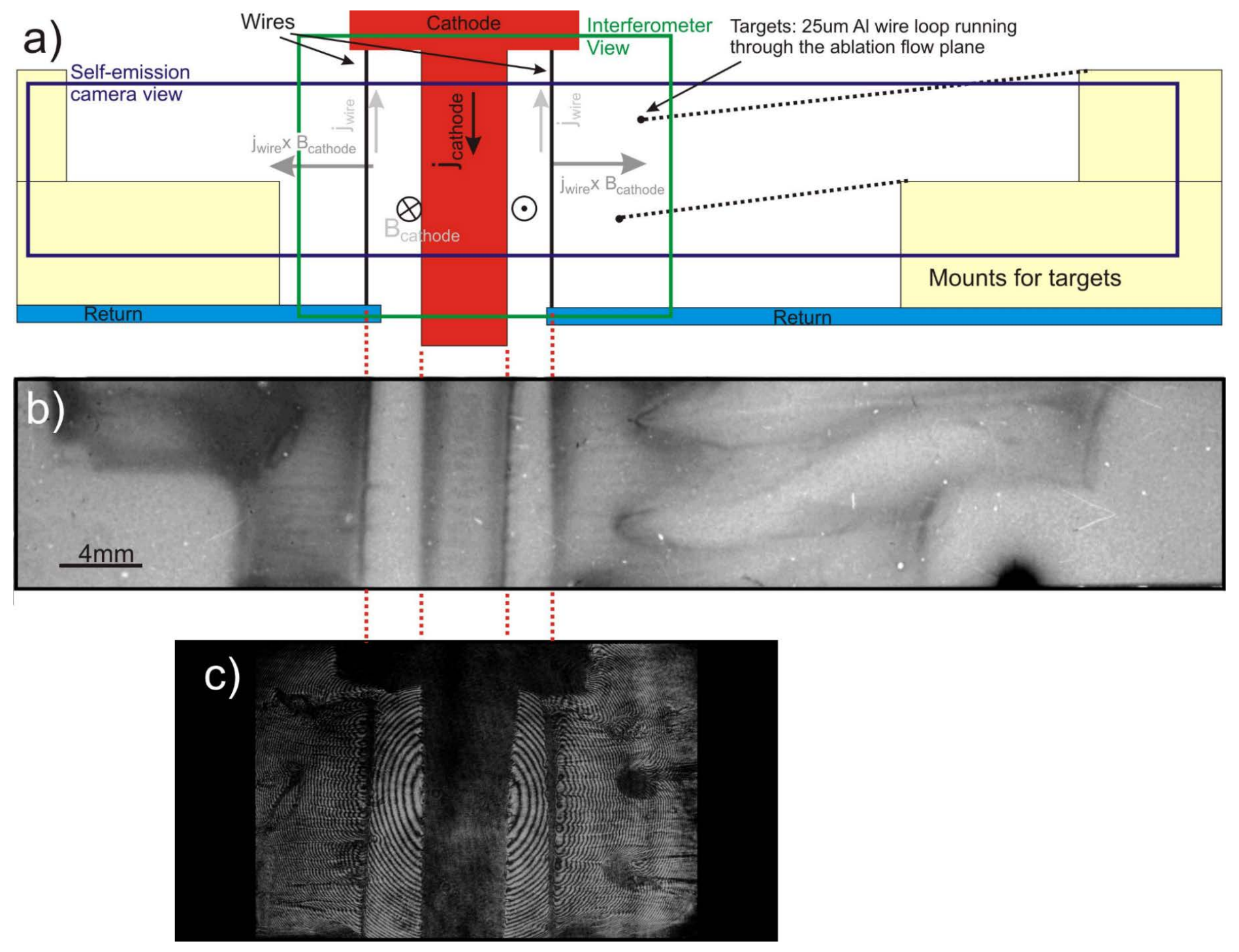
Figure 1: Photograph of the experimental setup on Cornell's XP machine (150ns, 300kA)

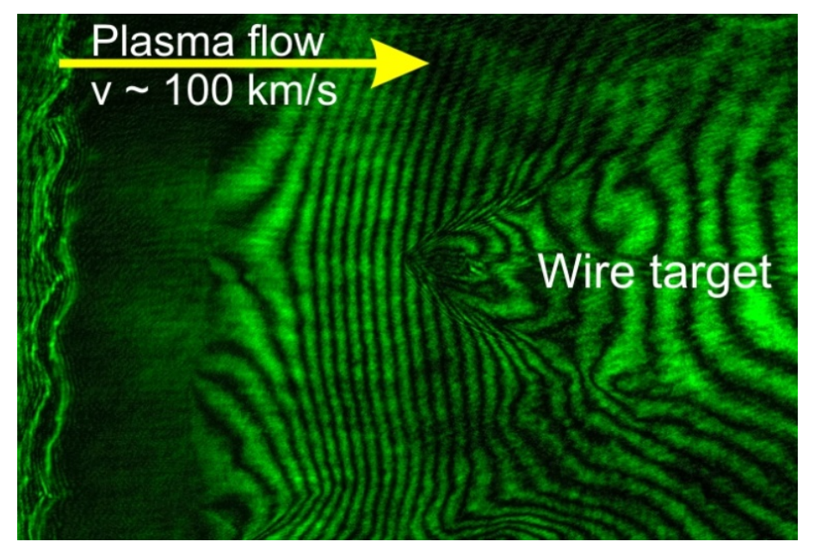
- Exploding wire arrays readily generate **J**x**B** accelerated flows from metallic wires using currents of >100kA
- The flow density can be estimated analytically [3] to ensure that the flow is collisional on the expected scale-length of the system (<0.5mm)

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

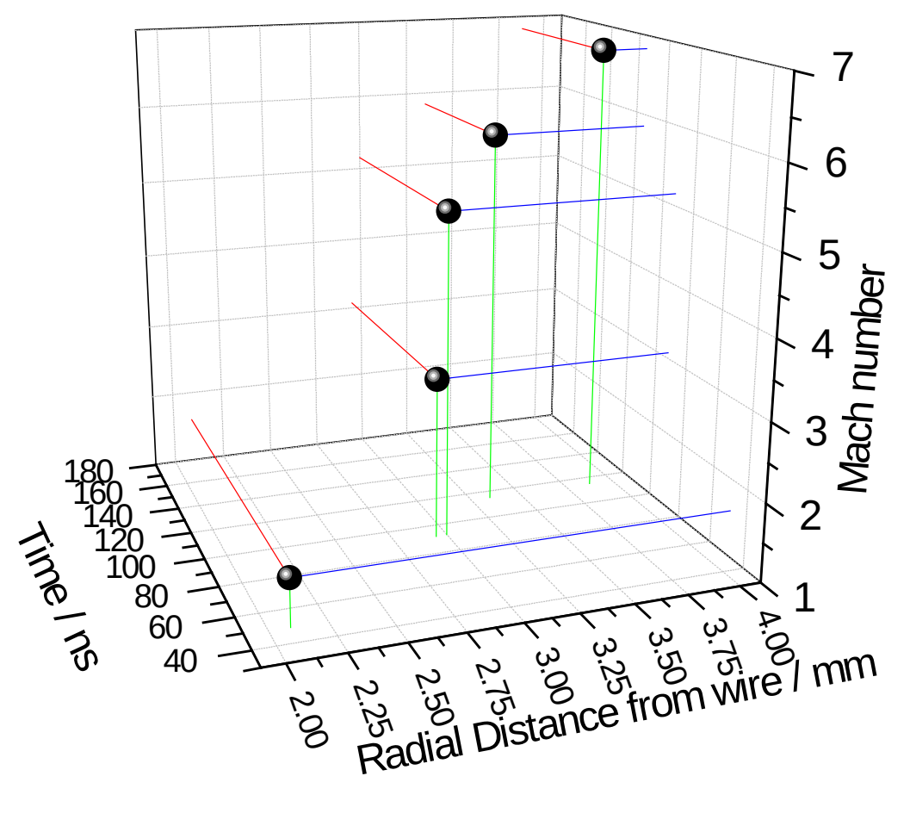
$$\lambda_{perp}=\frac{m_{ion}^2 v_{abl}^3}{8\pi Z^4 e^4 n_{ion}\ln\Lambda\sqrt{\pi/2}}$$



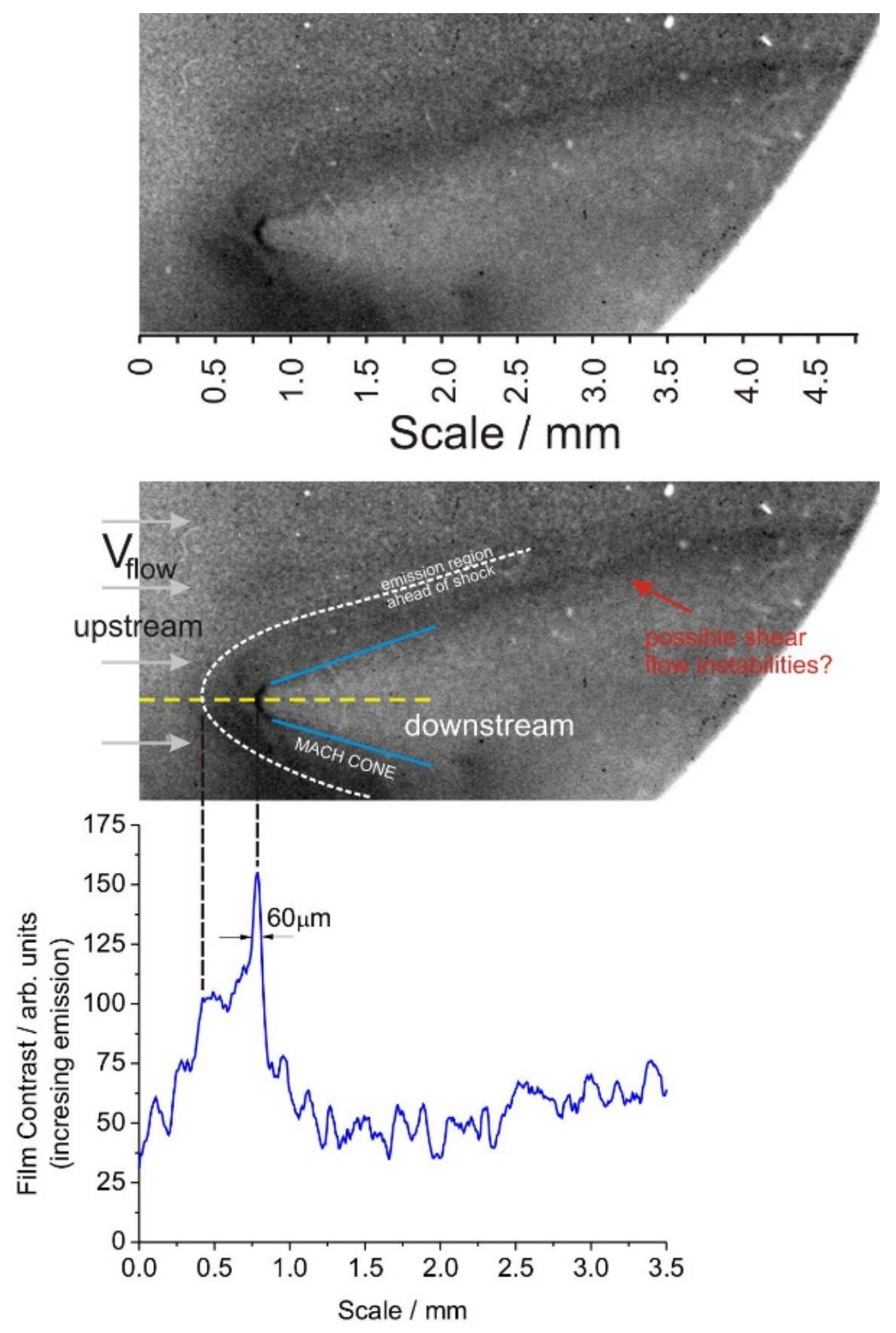




- High spatial resolution laser interferograms can give quantitative 2D areal electron density maps
- Mach number can be directly measured through sin(α)=1/M



- High compressibility means shock regions is too dense for laser to penetrate at late times
- Shock angle decreases with radial position – Mach number increasing
- If flow velocity is approximately constant, flow is cooling strongly
- High spatial resolution (60μm) self emission imaging shows narrow shock region and strongly cooling

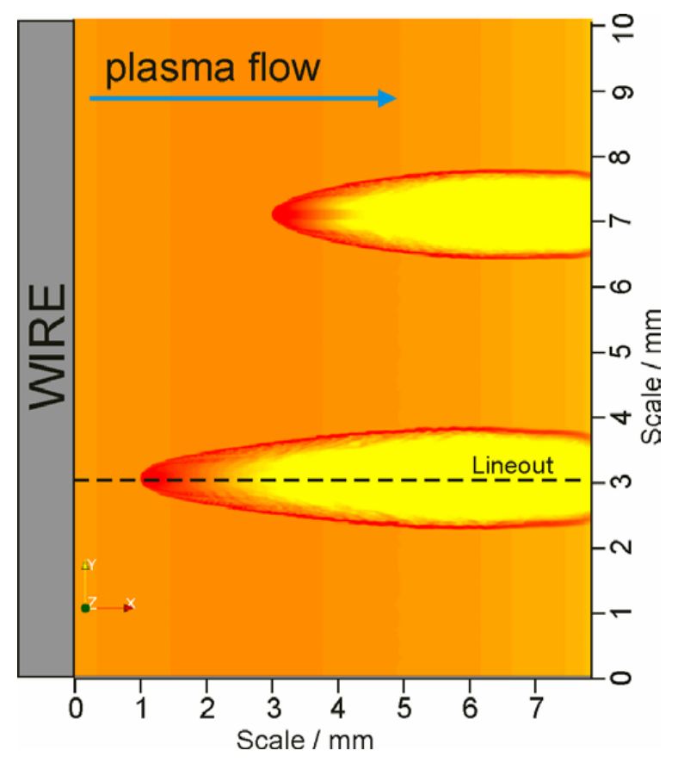


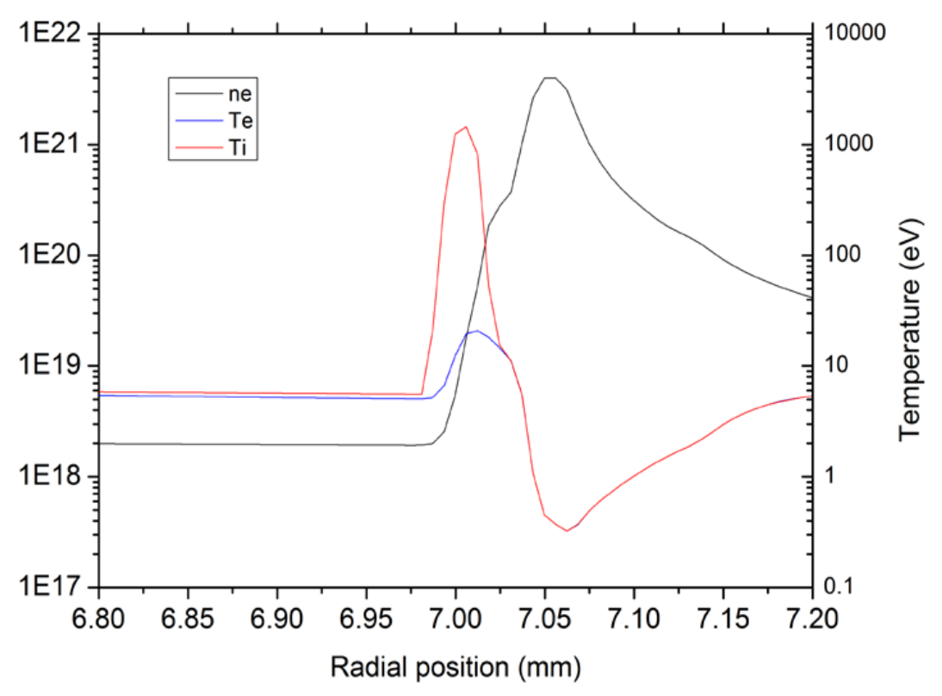
- Temperature at the impact region are of order 40 eV with rapid cooling to ~few eV behind the shock

$$\frac{T'}{T}=\frac{[(\gamma-1)M^2+2][2\gamma M^2-(\gamma+1)]}{(\gamma+1)^2 M^2}$$

Simulation work was carried out at Imperial College London using the 3D MHD code GORGON [5]

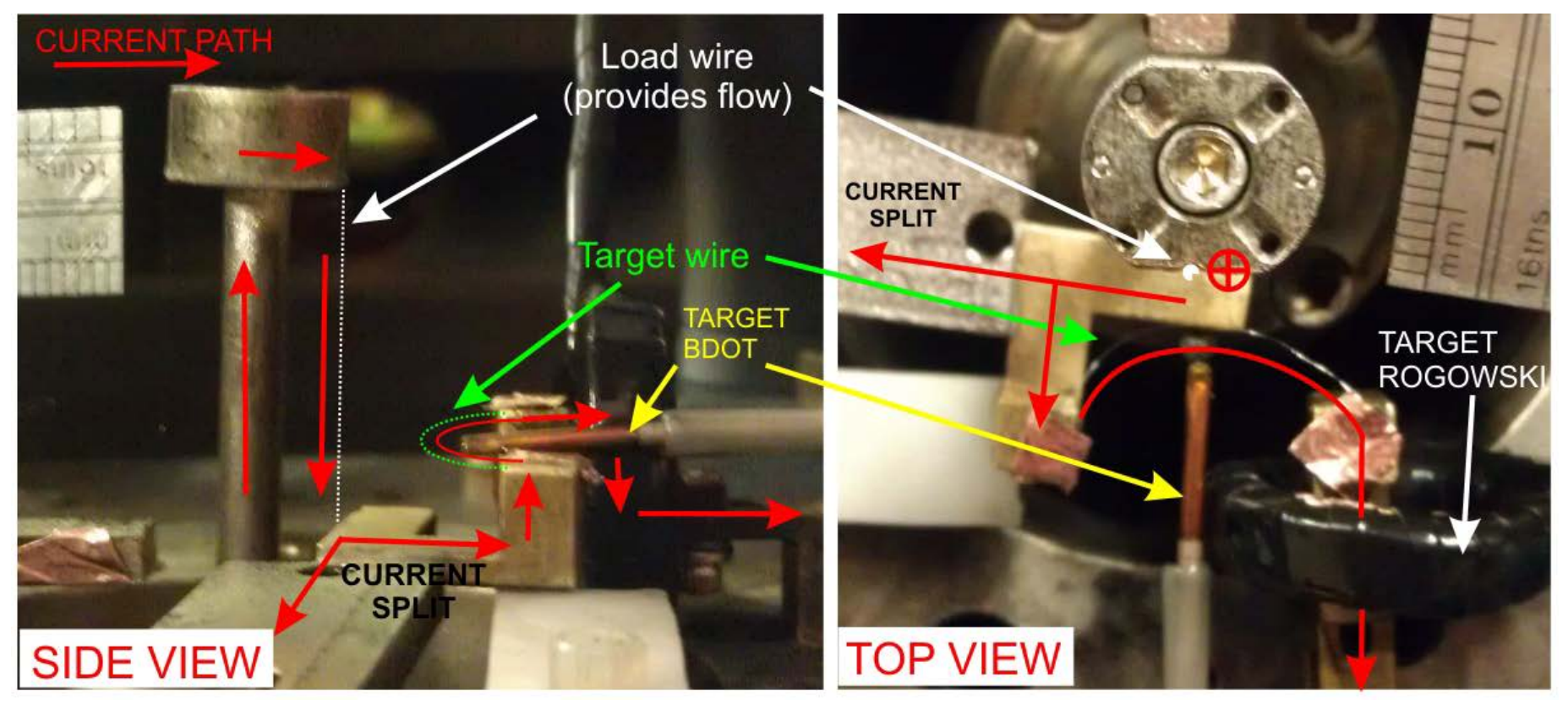
- Mass density plots from 2D simulation (6 μm cells) 3D showing ablating plasma impacting the target wires.
- Plasma parameters breadly in line with experiments
- Detailed radiation transport simulations underway



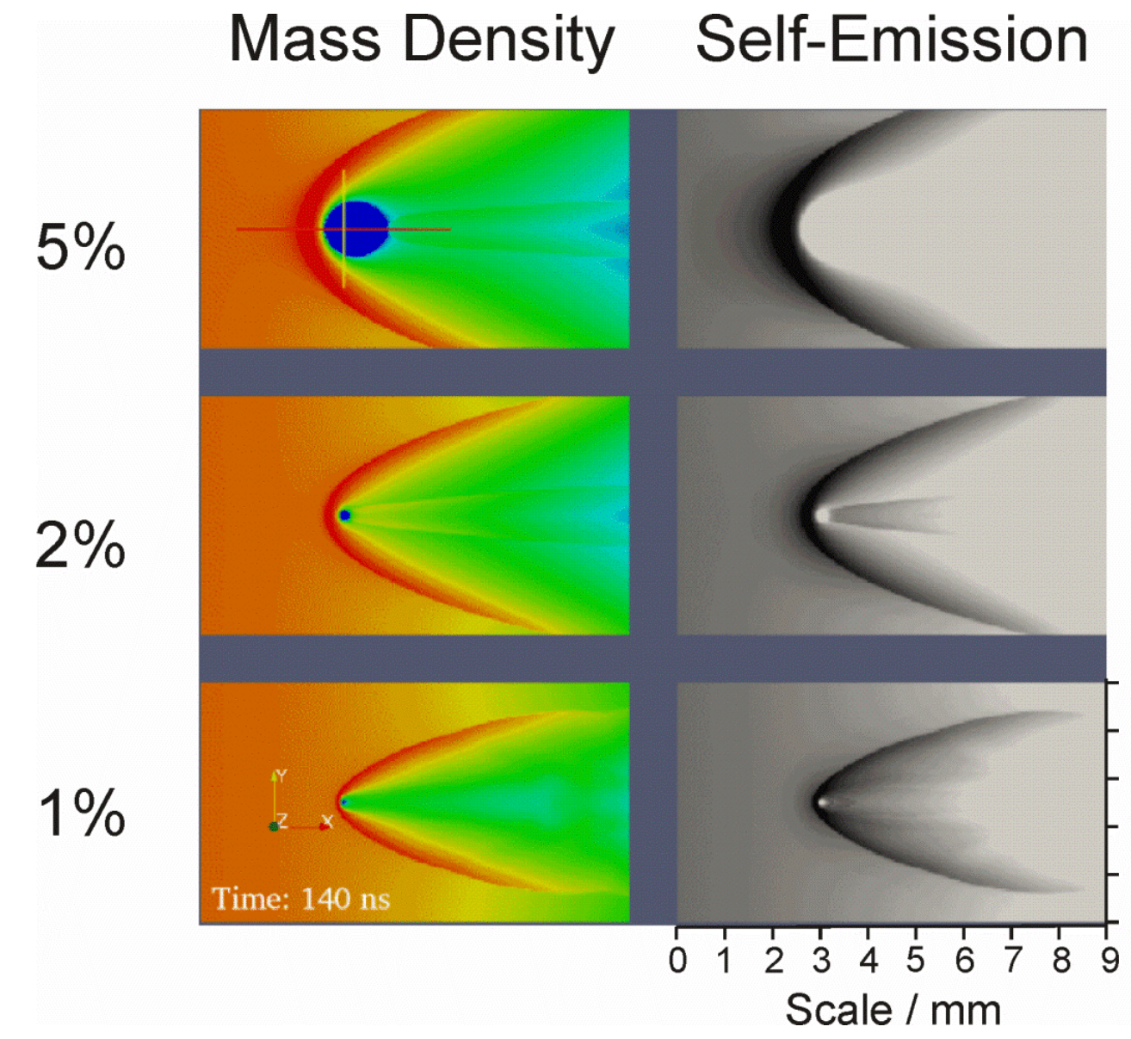


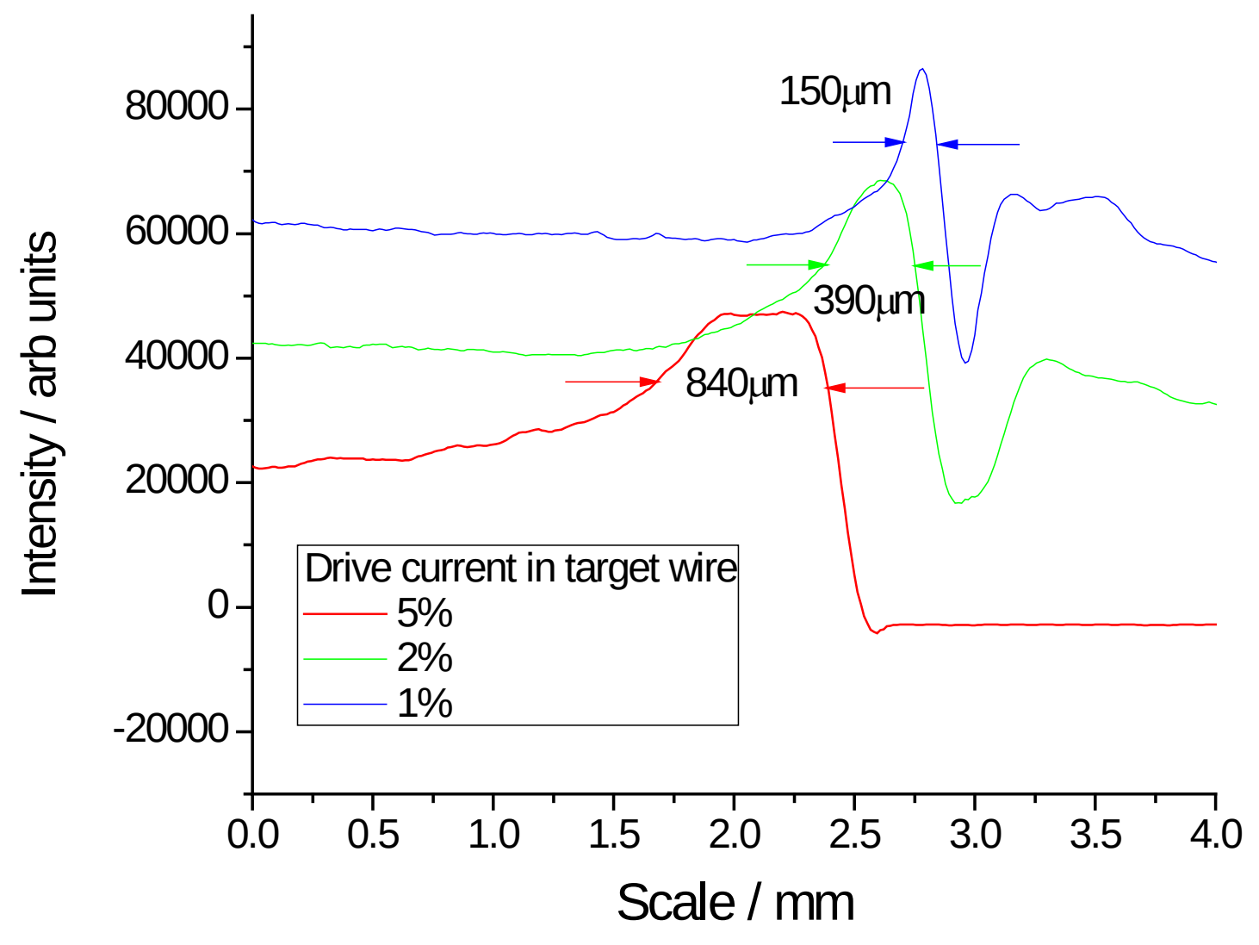
Magnetized Shocks

- Load and target wires both placed in series with drive current, or use inductive split to determine target current
- B-field >>10T possible at 1mm from target wire, and relatively controllable
- Alfvenic Mach number in the flow is ~2-3

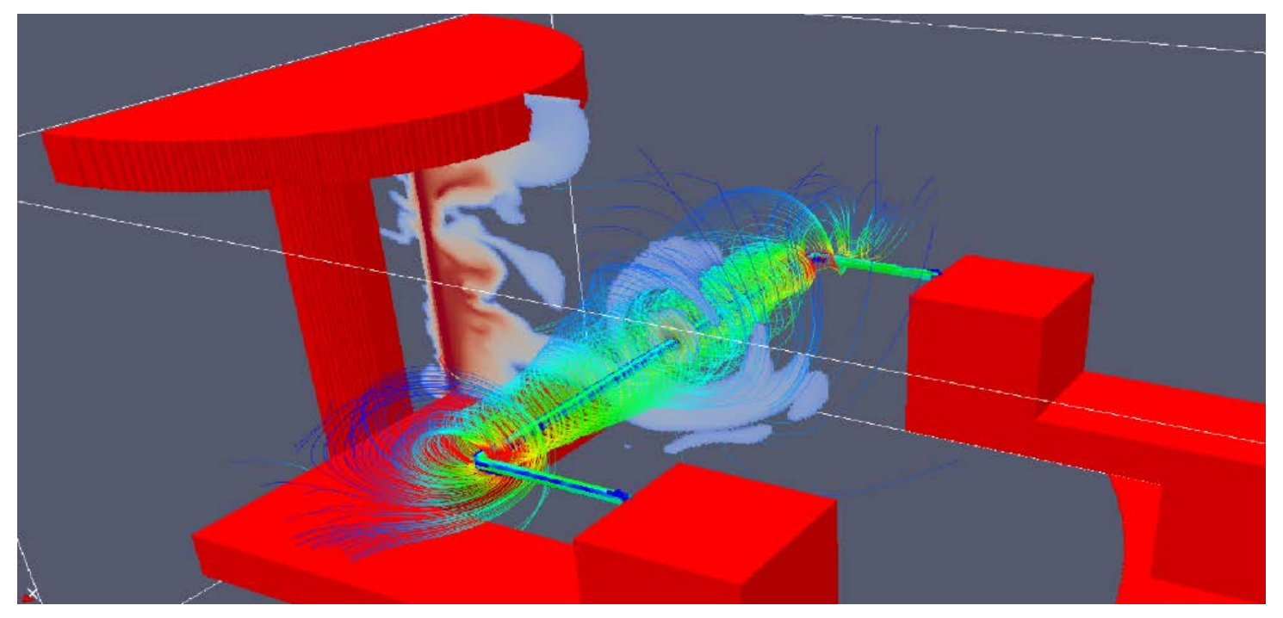


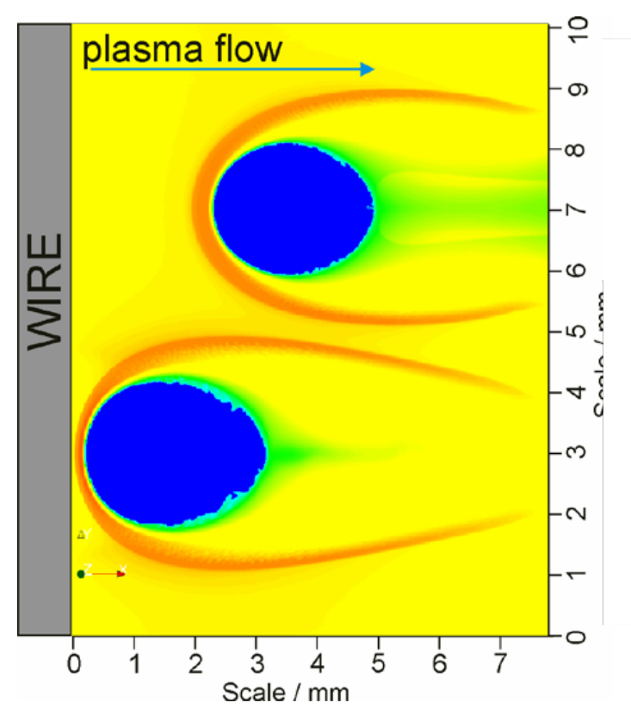
- At low B-field values simulation show a broadening of the shock front

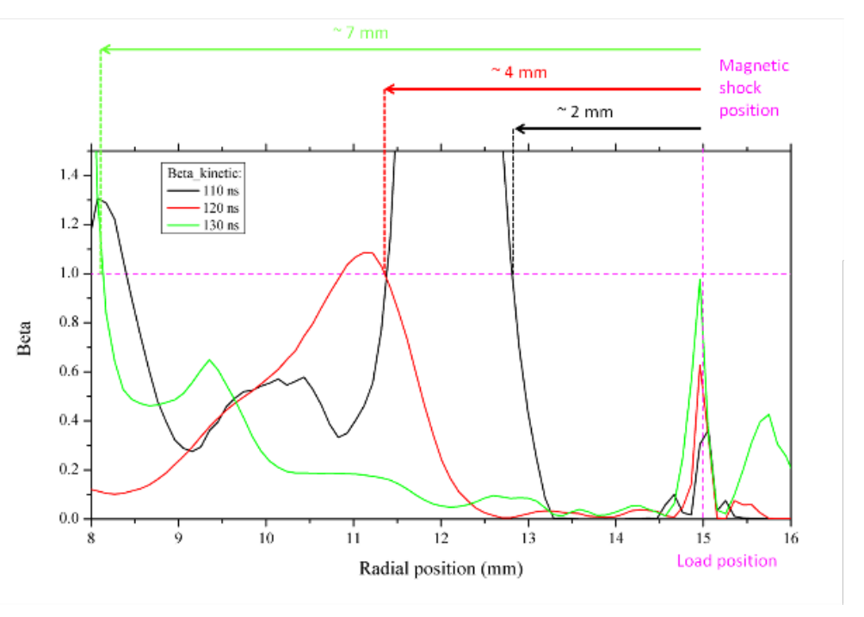




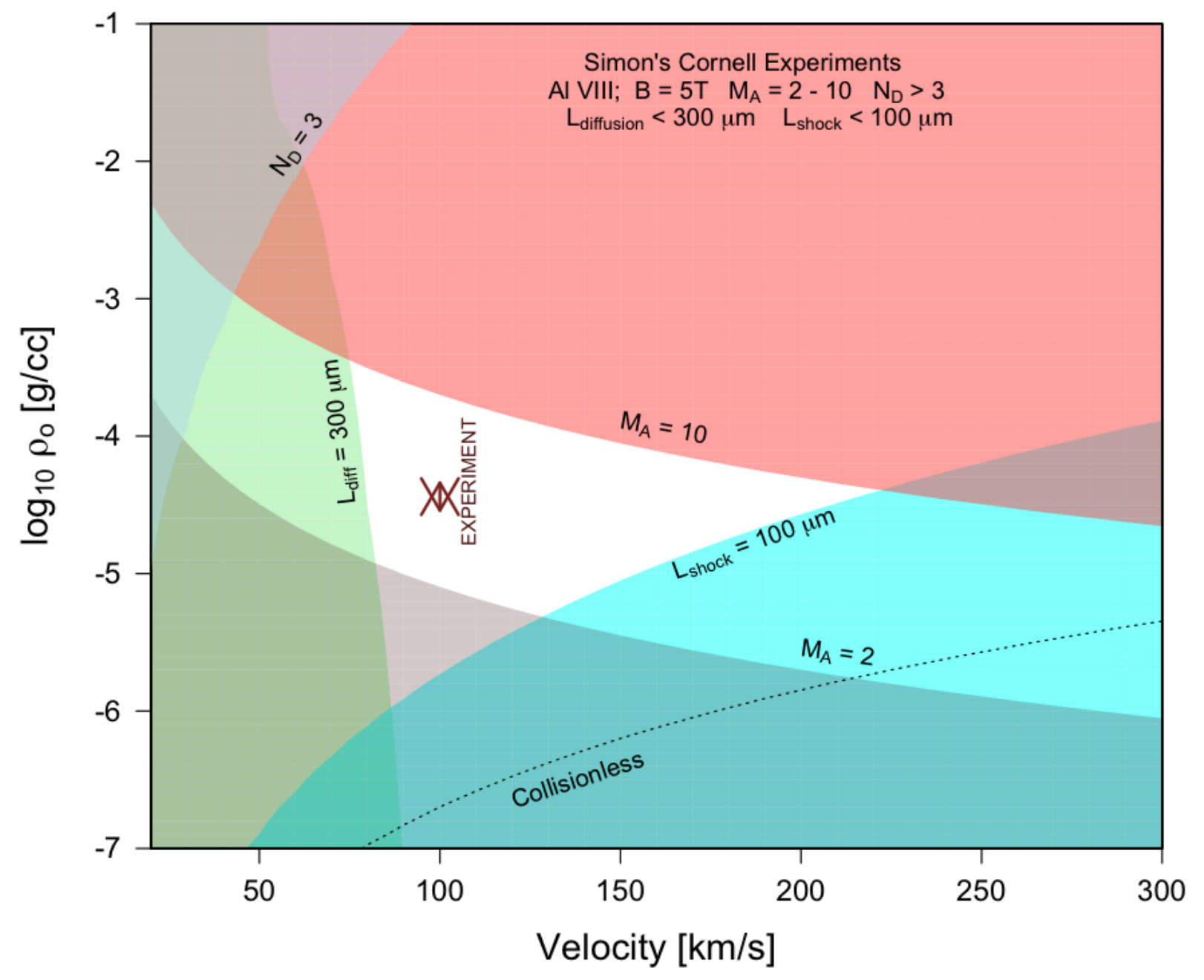
- At high B-field values, simltio ahow the magnetic pressure at the target dominates the bow-shock shape



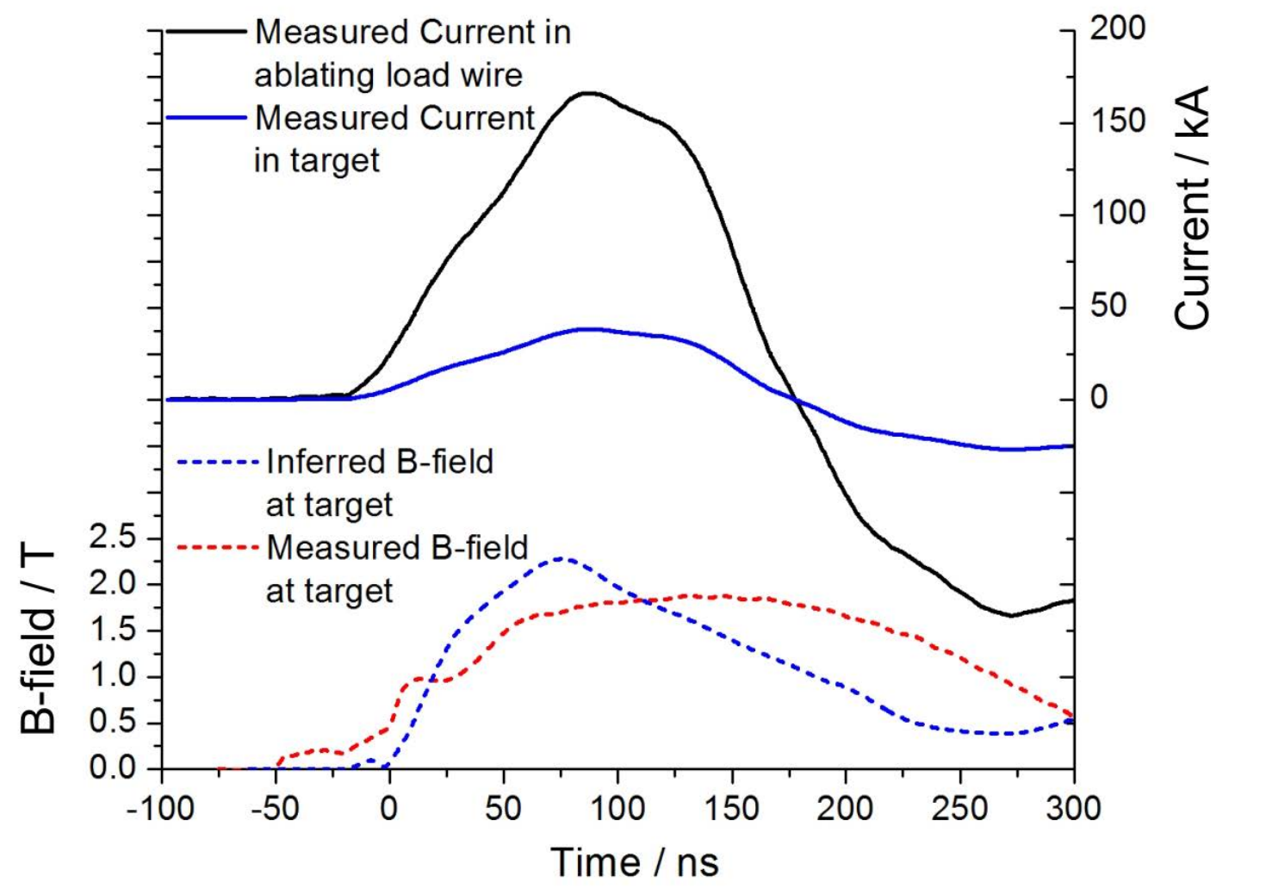




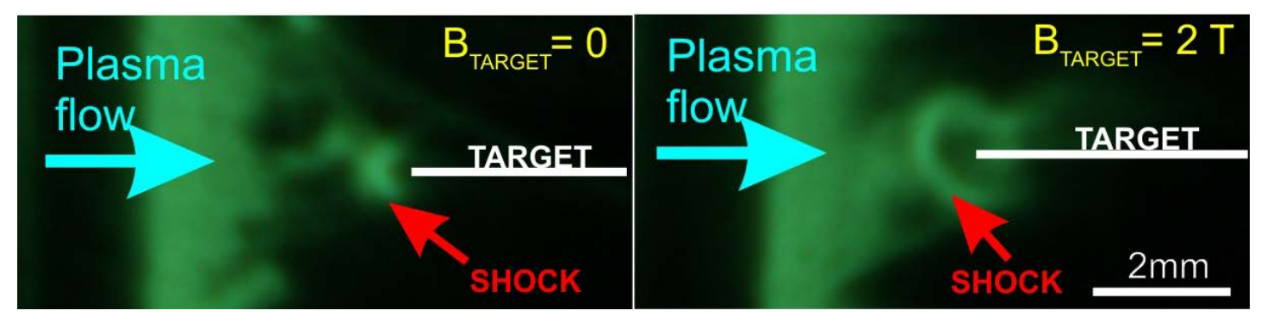
- 3D simulation showing mass density and B-field magnitudes along with high resolution 2D simulation of magnetized bow shock showing magnetically dominated region around target, and plots of the position of magnetized shock with time.
- Parameter ranges for experiment appear to be in a good regime for magnetized shock (see P. Hartigan poster)



- Initial experiments appear promising
- B-field close to target directly measured in each shot
- Clear difference observed in magnetized target case relative to hydrodynamic case



- Location of shock over time should move as the ratio of kinetic to magnetic pressure changes



Conclusions

- Exploding wire array system is an excellent candidate for generating bow shocks
- Hydrodynamic shock results show narrow shock region, cooling region and peak temperatures consistent with strong radiative cooling ($\gamma \approx 4/3$)
- Magnetically dominated shocks simulations promising, and experiments are underway.

References

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