# Experimental study of colliding plasma flows in the presence of an ambient magnetic field

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## Background

- To date, our observations of astrophysical objects have been limited, making it difficult to obtain a complete picture of many systems.
- Efforts have instead been focused on recreating the dynamics of astrophysical systems on a laboratory scale. How these systems evolve under magnetic fields and their dynamics surrounding collisions is an important topic of research. [1]
- We currently lack understanding of how hot, fast and dense plasmas interact in a collision, and also of a shock undergoing radiative cooling. Investigating these could inform us on jet-like outflows from young star objects.
- The plasmas expand into a strong magnetic field (~10 T), which is driven by the current flowing through the Z-pinch (shown in Fig. 1).
- The X-ray burst from a wire-array Z-pinch implosion is used to ablate plasma from silicon targets, following which the collision dynamics are investigated.

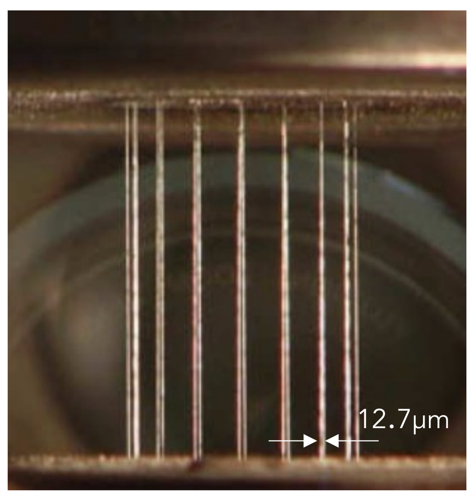


*Fig. 1. An aluminium 16-wire array Z-pinch (MAGPIE gallery). [2]*

## Project Aim

- Investigating plasma flows which are driven by the X-Ray burst from an imploding wire-array Z-Pinch. In particular, we want to explore the behaviour of the flow during and following collision, and the plasma structures formed.

## Diagnostics

- **Self-Emission Imaging:**
  - Optical imaging uses a fast-frame camera capable of taking 12 frames, with an exposure time of 5ns and a customisable inter-frame (15-30ns) spacing.
- **Laser Interferometry:**
  - Mach-Zehnder interferometry configuration which utilises a ND: YAG laser (EKSPLA SL321P). Probing wavelengths of $\lambda$ = 532nm and 355nm.

## Experimental Setup

- The pulsed-power generator used in our experiments was the Mega Ampere Generator for Plasma Implosion Experiments (MAGPIE), shown in Fig. 2.

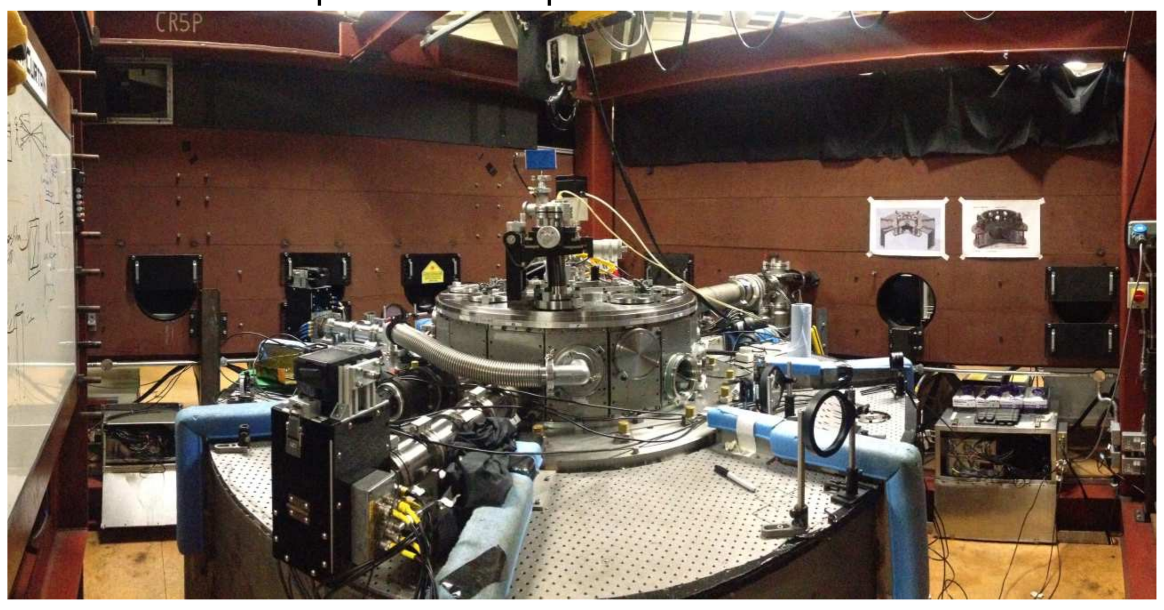

*Fig. 2. Image of MAGPIE from within the discharge chamber, obtained from Imperial College London website (MAGPIE gallery). [2]*

- The system was designed to study the characteristics of the colliding plasmas (displayed in Fig. 3), where an imploding wire-array z-pinch was used to drive ablated plasma flows from their silicon targets.
- A current pulse (1MA over 240ns rise time) was applied on the wire array, generating X-rays which ablate the plasma from the targets, as well as inducing an azimuthal magnetic field ($B_\varphi$~10T), ambient in the load chamber.

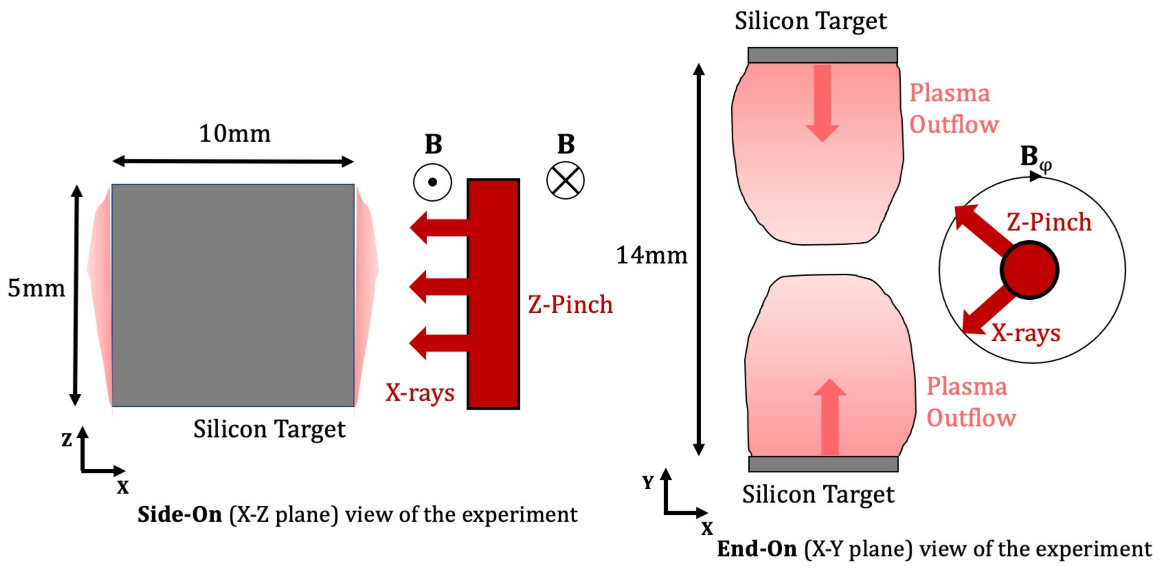


*Fig. 3. Side-on and end-on views of the experimental setup inside the vacuum chamber of MAGPIE.*

- Moreover, the geometry of the target holders designed along with the experimental setup enabled the plasma's behaviour to be monitored using specifically designed diagnostics.

## Results & Data Analysis

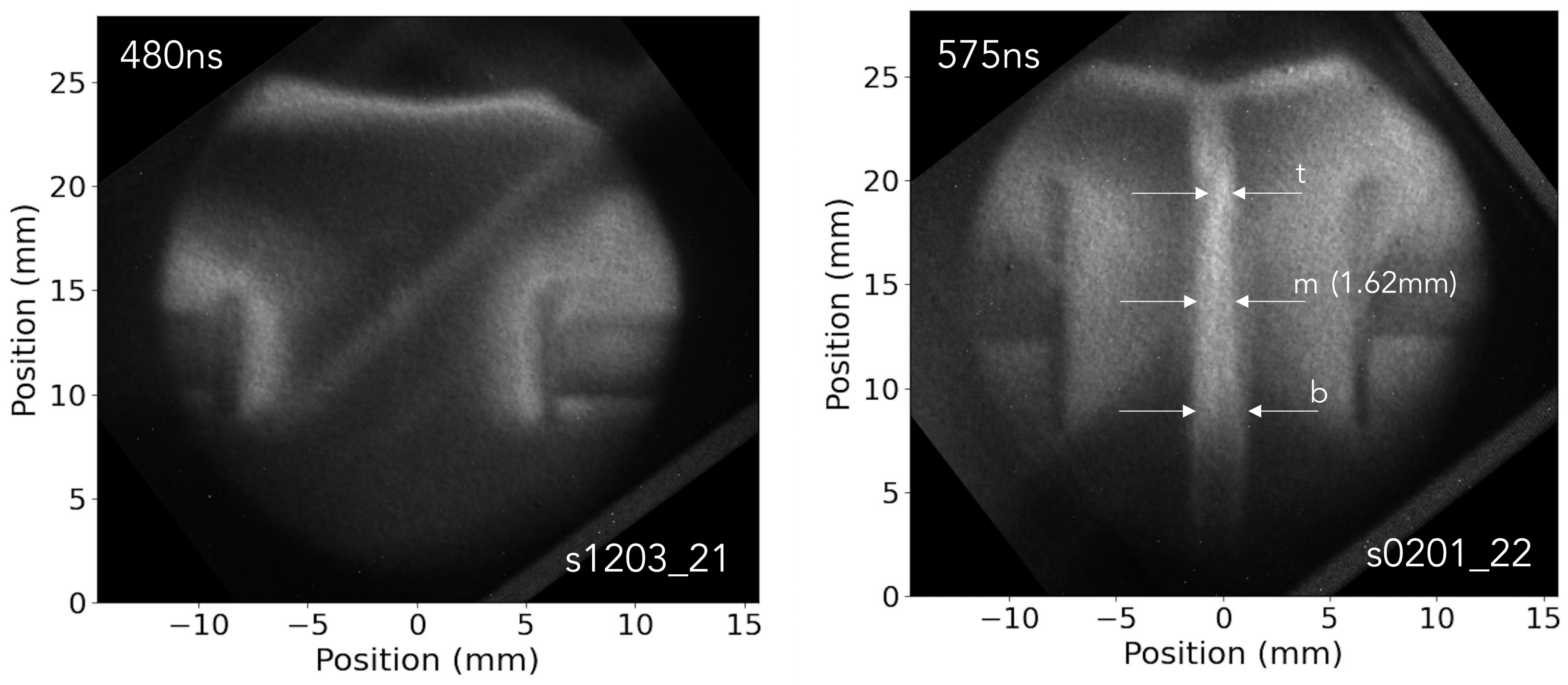


*Fig. 4. Self emission images from two separate shots and experimental times.*

### Self Emission:

- The intensity of the emitted light by the plasma strongly correlates to the electron density.
- Using this, we explored the evolution of the plasma dynamics and calculated the velocities of the plasma fronts prior to the shock.
- From our shot, we could see clear evidence of a reverse flow following shock formation. Fig. 5 shows the expansion of the shock region.

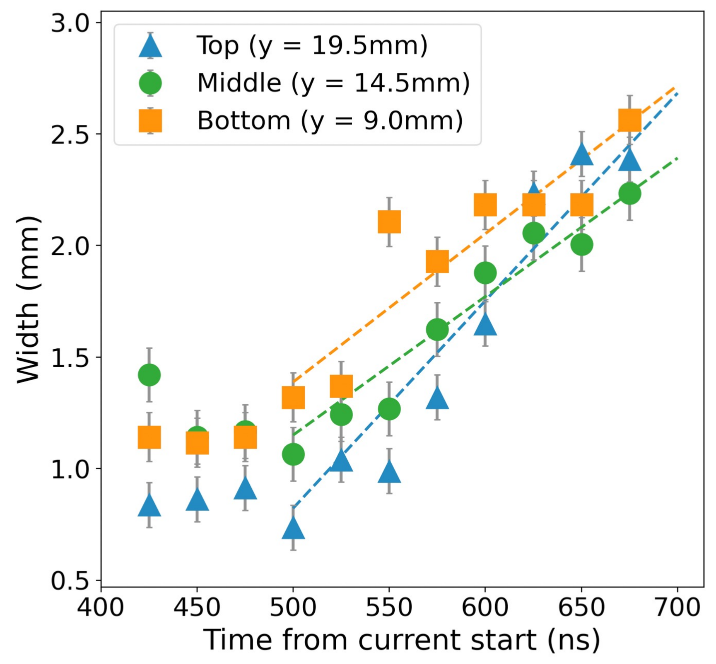


*Fig. 5. Width of shock region over time. Probed regions shown by corresponding letters (t, m, b) in Fig. 4.*

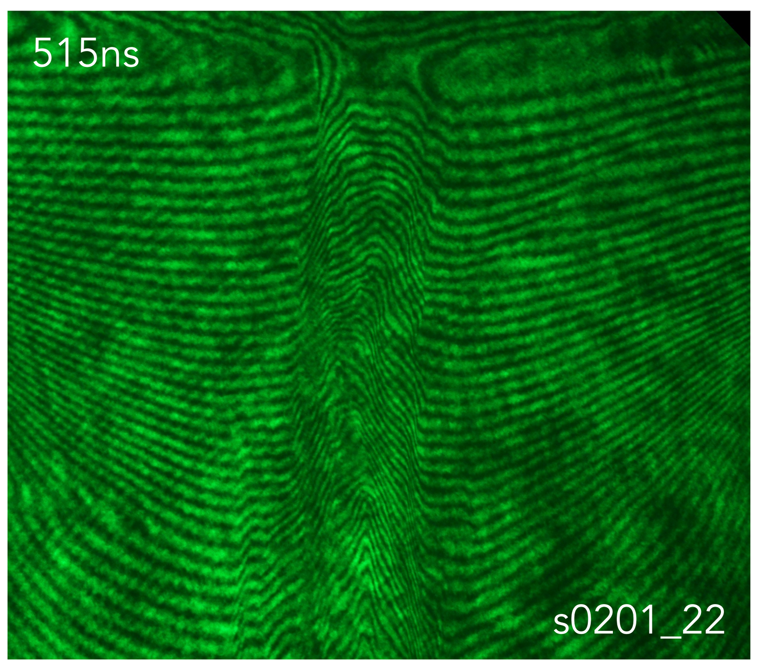


*Fig. 6. Interferogram ($\lambda$ = 532nm) of shock region.*

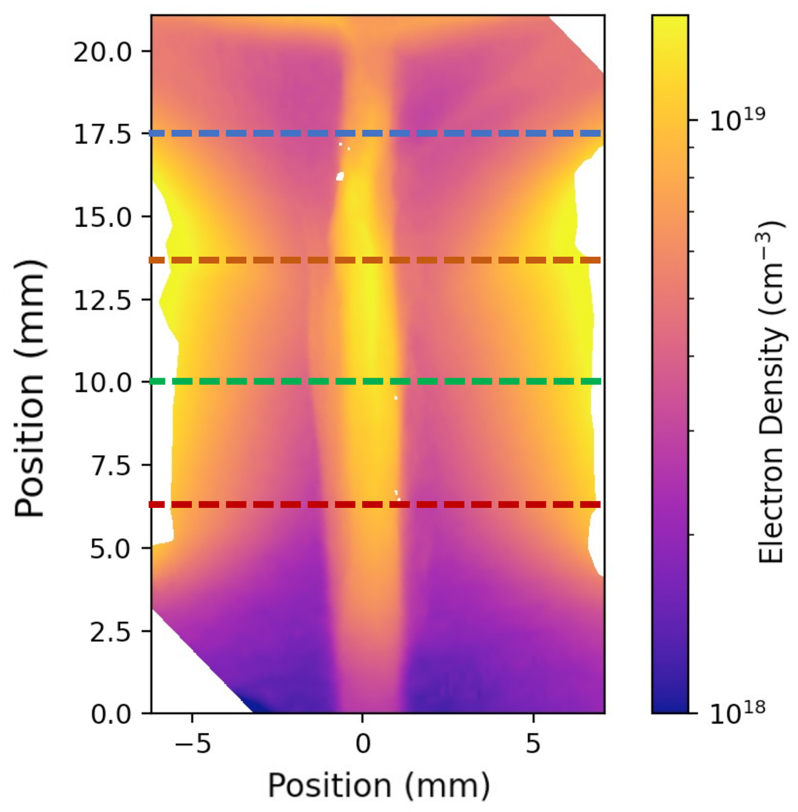


*Fig. 7. Electron Density map (logarithmic scale) of shock region.*

### Interferometry:

- Interferogram of the interaction region shown in Fig. 6.
- As fringe shift is related to electron density, we can use the interferogram to find the electron density of the plasma.
- The fringes were traced manually to generate a contour map, and triangulation [4] was used to create an interpolated phase map. From this a path-integrated free electron density map is created (shown in Fig. 7).

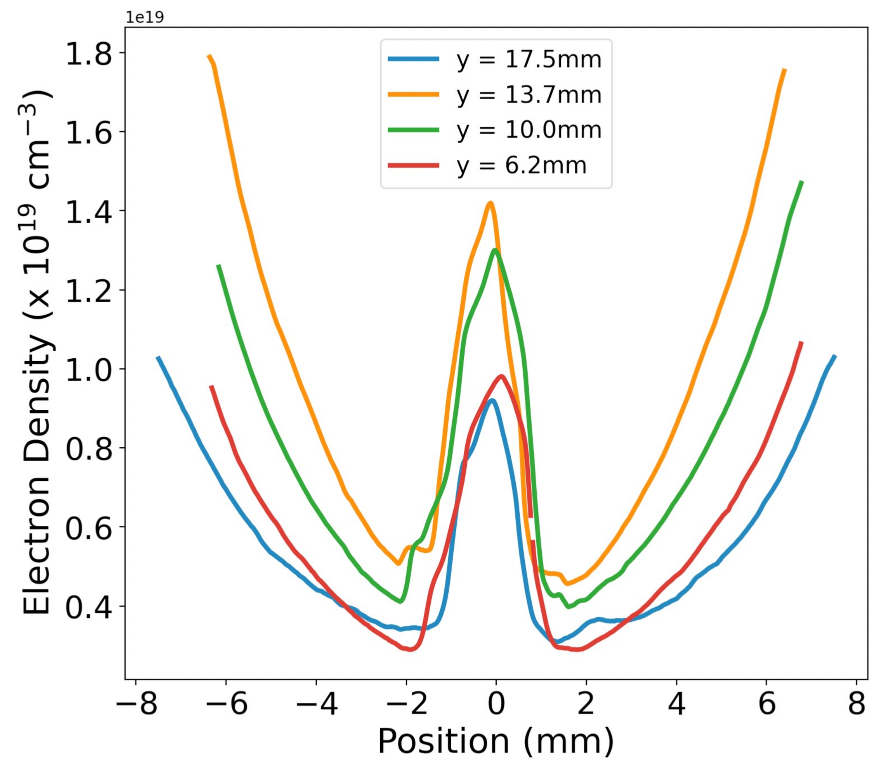


*Fig. 8. Lineouts of electron density map (75px wide), with colours corresponding to the dashed lines in Fig. 7.*

## Continuation

- Using equation 1 we will analyze $\gamma$, the ratio of compression of the plasma, using the analyzed Mach number and the density variations in the plasma fronts and the shock. [5]

$$\frac{\rho_2}{\rho_1} = \frac{M_u^2(\gamma+1)}{M_u^2(\gamma-1)+2} \qquad (1)$$

where:
$\rho_2$ = density within shock
$\rho_1$ = density upstream of shock
$M_u$ = Mach number

- Further analysis could be carried out by using Thomson scattering and Faraday rotation imaging diagnostics, or potentially altering the material of the target to see if the collision behaviour is altered.

## References

[1] Remington, B., Drake, R. and Ryutov, D., 2006. Experimental astrophysics with high power lasers and Z pinches. Reviews of Modern Physics, 78(3), pp.755-807.

[2] Imperial College London, 2021. MAGPIE Gallery. [online] Available at: https://www.imperial.ac.uk/plasma-physics/magpie/gallery/.

[3] G.F. Swadling, S.V. Lebedev, G.N. Hall et al., 2014. Diagnosing collisions of magnetized, high energy density plasma flows using a combination of collective Thomson scattering, Faraday rotation, and interferometry, Rev. Sci. Instrum. 85.

[4] J D Hare et al., 2019. Two-colour interferometry and Thomson scattering measurements of a plasma gun, Plasma Phys. Control, Fusion, 61.

[5] R. P. Drake, L. Davison, and Y. Horie, 2006. High-Energy-Density Physics: Fundamentals, Inertial Fusion, and Experimental Astrophysics.