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Collisions of Supersonic Magnetised Plasma Jets

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Background

- Supersonic, magnetised plasma jets in Herbig-Haro objects can travel at speeds in excess of 200km/s [1]
- Outflows in such objects with higher velocities can overtake and interact with slower streams
- These jet collisions are characterised by radiatively cooled bow shock structures
- We present a method to recreate and observe such structures in the lab using Imperial's MAGPIE facility

Figure 1: Hubble telescope image of Herbig-Haro object HH47. Image credit: NASA [2]

Objectives and Setup

Aim: Design and test hardware to recreate plasma jet collisions. Our design should incorporate:

- Control over the polarity of the confining azimuthal magnetic field
- Collision midpoint located at the standardised height for laser diagnostics
- Minimized inductance and potential for electrical breakdown
- Sufficient field of view for diagnostic equipment

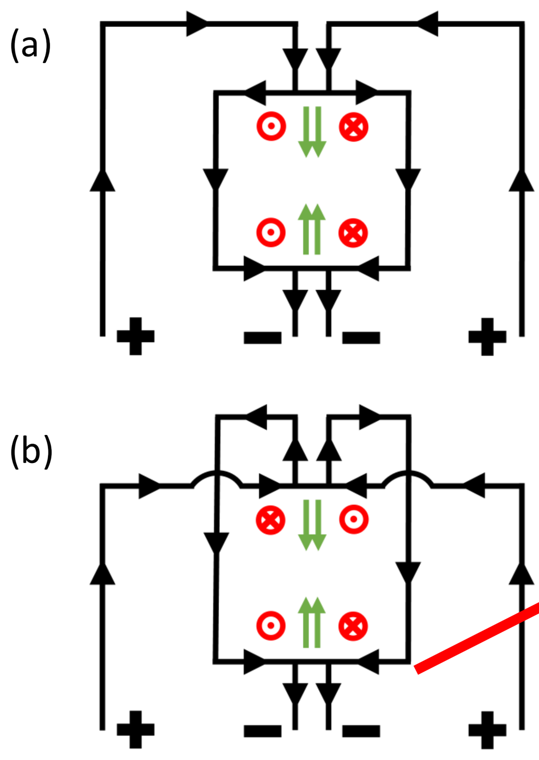


Figure 2: Schematic of current flow in (a) parallel and (b) antiparallel configurations.

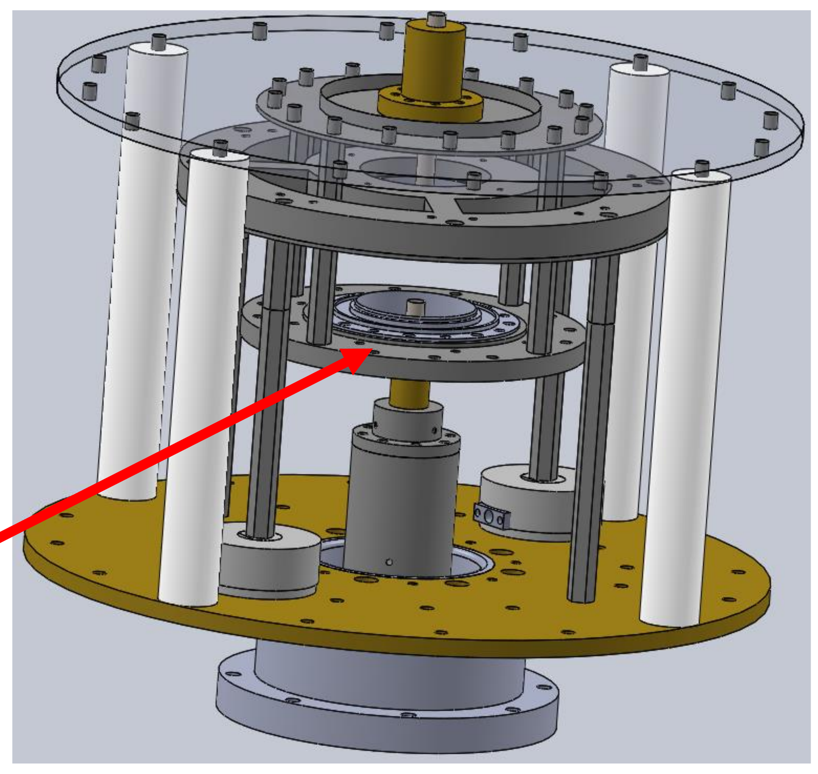


Figure 3: Initial SOLIDWORKS design for antiparallel magnetic fields

MAGPIE passes a 1.4MA current into load. We focus on the following diagnostics:

- Rogowski Probes: Wire coils sensitive to rate of change of current in the load
- MITL B Dots: Wire coils located below anode showing possible breakdowns
- XUV Imaging: Images of Extreme Ultra Violet (XUV) self emission from the plasma jets

Antiparallel B Fields

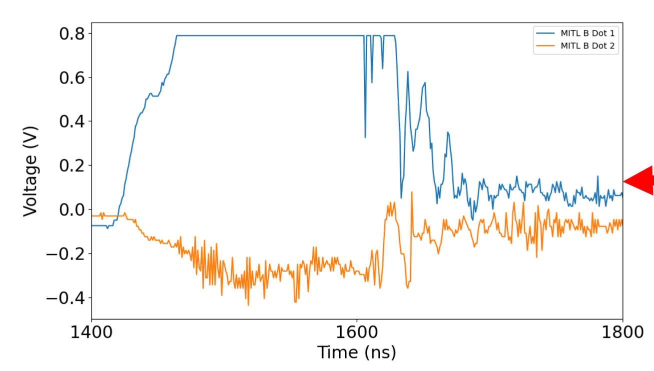


Figure 4: MITL B dot measurement after initial antiparallel shot

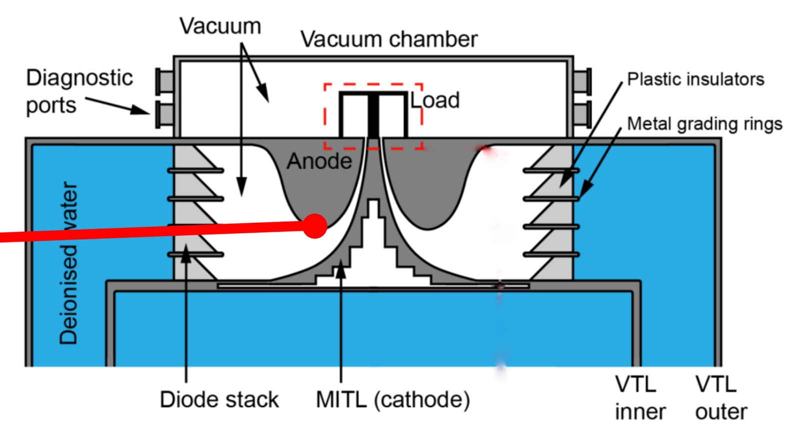


Figure 5: Cross-section of the MAGPIE facility with B Dot location indicated [3]

First shot:

- MITL B Dot measurements indicate lack of a return current signal
- Results suggest high inductance of the load caused breakdown between cathode and anode in the chamber
- Reduce inductance by modifying current path to enclose smaller volume of flux

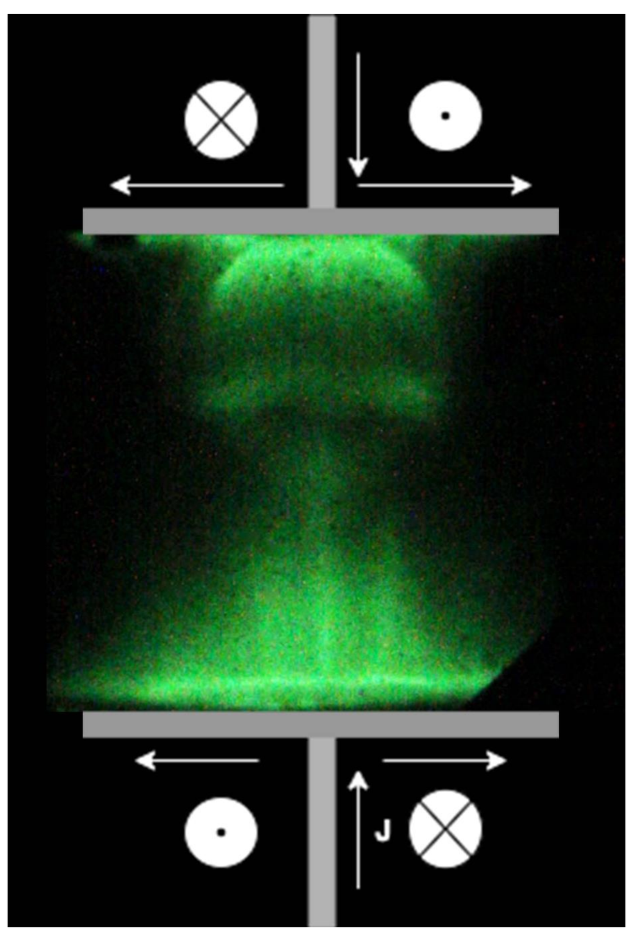
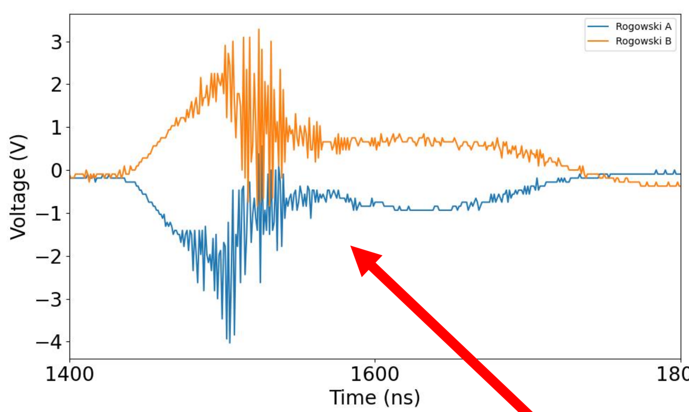


Figure 6: XUV image of antiparallel collision. Bow shock is observed near the top foil.



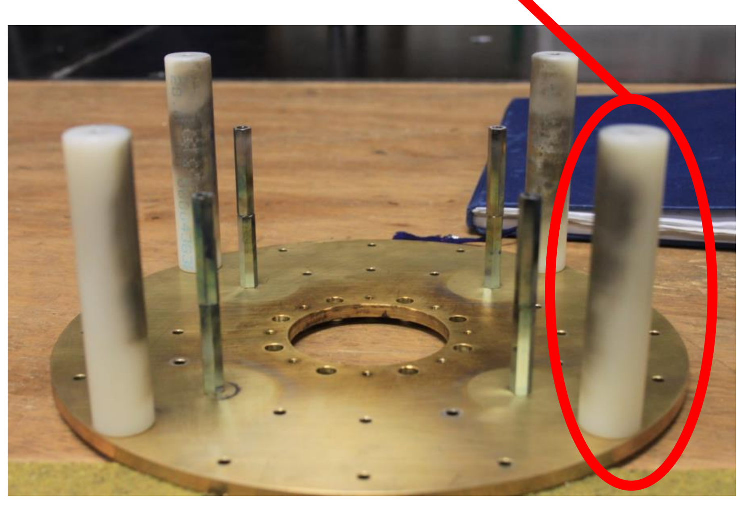


Figure 7 (Top): Rogowski Probe measurements from second shot showing initial current rise followed by breakdown.

Figure 8 (Bottom): Post shot picture showing possible conducting path on Nylon post

Second shot:

- B Dots imply no breakdown in MITL, however Rogowski's suggest breakdown in the load
- Bottom jet propagates but top foil only produces ambient plasma
- Bow shock observed when bottom jet reaches top foil location

Setup	Inductance (nH)
Antiparallel 1	98 ± 9
Antiparallel 2	33 ± 3
Parallel	40 ± 5

Table I: Inductance estimates for each shot setup. Calculated using formula from Burdiak *et al* [4]

Parallel B Fields

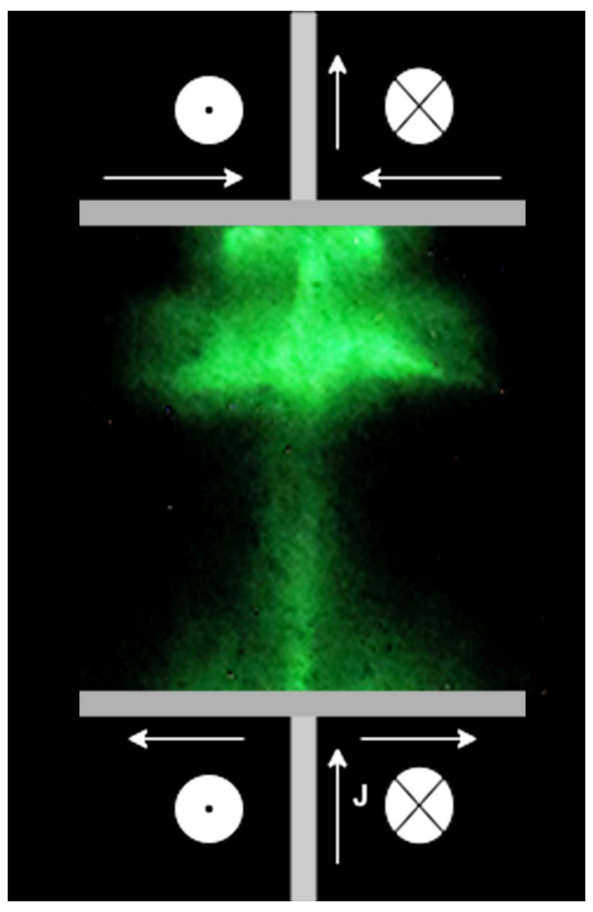


Figure 9: XUV Image of parallel jet collision. Top jet formed with slower velocity

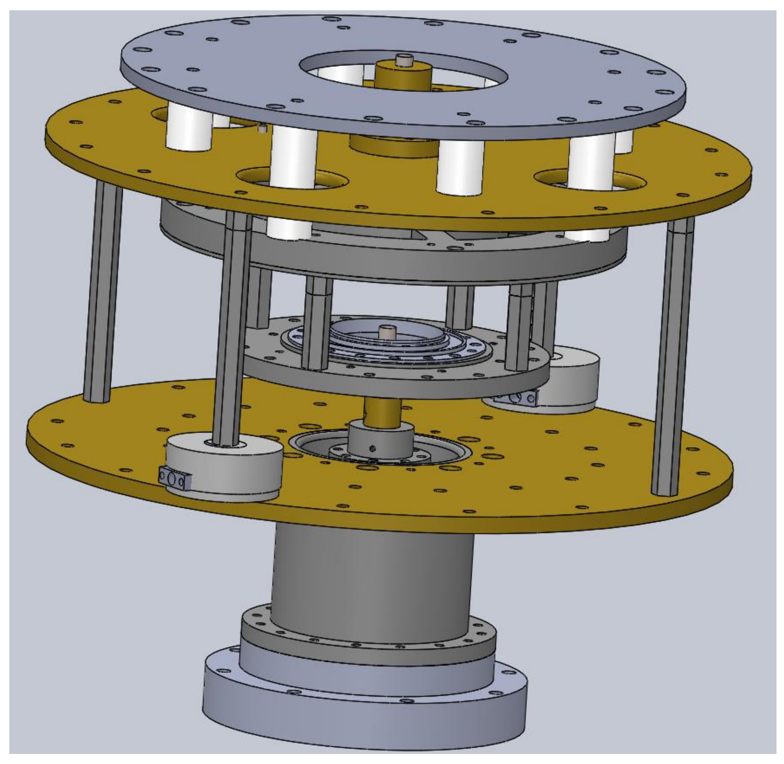


Figure 10: Updated design for parallel setup. Nylon posts have been repositioned to reduce contact with plasma. A collar has been attached to raise the height of the anode plate. Posts have been shielded from UV to prevent surface plasma forming conduction path.

Result

- Weak top jet produced, as indicated by position of collision above foil midpoint
- Higher degree of collimation from bottom foil ablation
- MITL B Dots indicate no breakdown in diode stack
- Rogowski Probes similar to previous experiment, indicating breakdown within the load

Analysis

- Unequal jet velocity suggests reduced current through top foil caused by breakdown between metal plate and top foil

Future Work

Redesign

- Plastic plate attached to top foil to minimize breakdown
- Edges of metallic plates filleted to reduce sharp edges

Measurements of Plasma Conditions

- Parallel and antiparallel experiments with updated designs
- Faraday rotation and interferometry diagnostics to determine magnetic field strength and plasma electron density
- Multi-frame optical self-emission imaging to better understand dynamics of interaction
- Thomson scattering laser diagnostic to measure jet velocity, and electron and ion temperatures via Doppler broadening

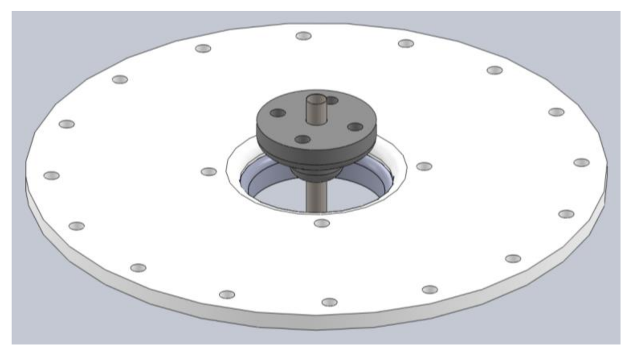


Figure 11: Downwards angle view of redesigned plastic place and its positioning relative to top foil

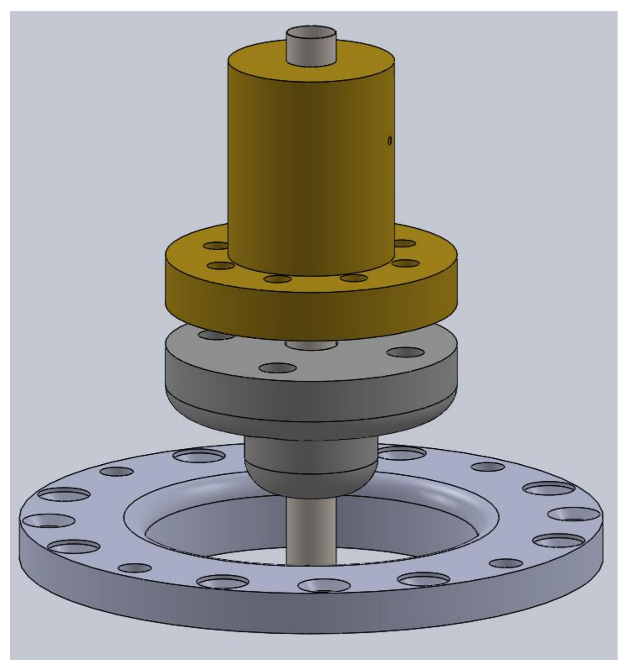


Figure 12: Updated foil holder and alignment piece with curved edges

Summary

- Usage of pulsed-powered generator requires careful design of load to satisfy constraints for system to operate correctly
- Antiparallel shots showed formation of bottom jet and bow shock but breakdown caused top jet to fail
- Parallel shots also displayed signs of breakdown in the load causing top jet to propagate much more slowly
- Future shots should have fillets wherever sharp edges are present to minimise risk of breakdown
- Design for bottom foil is currently being used by researchers in jet-obstacle interaction experiment

References

[1] *S. Lebedev et al, Plasma Physics and Controlled Fusion, 2005*
[2] *NASA et al, 1995*
[3] *G.C. Burdiak, PhD Thesis, 2012*
[4] *G.C. Burdiak et al, Physics of Plasmas, 2013*