Laboratory Study of Arched Plasma Eruptions in a Sheared Magnetic Field

Kamil Sklodowski[1], Shreekrishna Tripathi[1], Troy Carter[1]

[1]*Basic Plasma Science Facility, University of California - Los Angeles*

Poster #52

SUMMARY

- Evolution of a kink-stable arched magnetized plasma is studied in the presence of a nearly horizontal overlying magnetic field. The experiment was designed to capture the essential dynamics of arched plasma on the Sun
- Application of uniform background field introduces magnetic shear and leads to eruptive events. Signatures of eruptions are observed across all diagnostics used in experiments presented here (seen in density, magnetic field, temperature and plasma flow data).
- The arched plasma evolving in a sheared magnetic field ejects a flux rope in direction perpendicular to the lateral symmetry plane of the arch.
- The ejected flux rope carries a short-lived supersonic plasma flow away from the arch and a longer persisting electrical current.
- Eruption takes place during the initial stages of arched plasma evolution and lasts around few tens of Alfven times.
- Post-eruption, arched plasma becomes steady-state. A persisting smaller 'leakage' electrical current and plasma flow away from the arch is observed.

THE EXPERIMENT

- Arched plasma structures are common in solar atmosphere (solar prominences, coronal loops); oftentimes lead to eruptive events (e.g.: CME, solar jets, solar flares).
- These eruptive events are still difficult to forecast, and the exact nature of processes and mechanisms leading to solar eruptions is an open area of research.
- The experiment at UCLA was built and tuned to capture the essential physics of arched plasma on the Sun

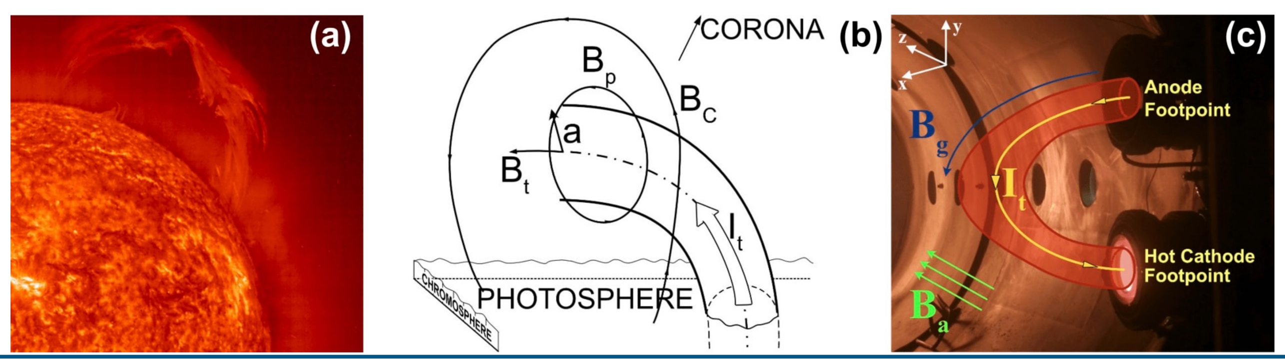


Figure 1: (a) A solar prominence observed in the extreme ultraviolet (EUV) wavelength of 304 Å by SOHO spacecraft on 28 March 2000 (Credit:NASA). (b) Schematic of a model flux rope in solar corona. (c) Photograph of the experimental setup depicting its main features

Plasma parameters were scaled down appropriately such that experiment is relevant to the solar case

	Solar Prominence	Laboratory Arched Plasma
Plasma β	$10^{-2} - 10^{-4}$	$10^{-1} - 10^{-3}$
r/r_i	$10^{9} - 10^{10}$	10^{2}
Lundquist number	$10^{12} - 10^{14}$	$10^{3} - 10^{4}$
Experiment time scale / τ_A	150	200
Resistive diffusive time / τ_A	10^{10}	>500
Aspect ratio	5	3

Table 1: Typical plasma parameters for this experiment and relevant solar structures.

Experimental Setup:
- The ambient field (< 50 G) is generated by outside coils along the cylindrical axis of the device (z-axis).
- Typical electric potential difference between electrodes was around 400 V.
- An arched magnetic field was produced by the set of coils installed on electrodes. The strength of that field was on order of 10^3 Gauss at footpoints.

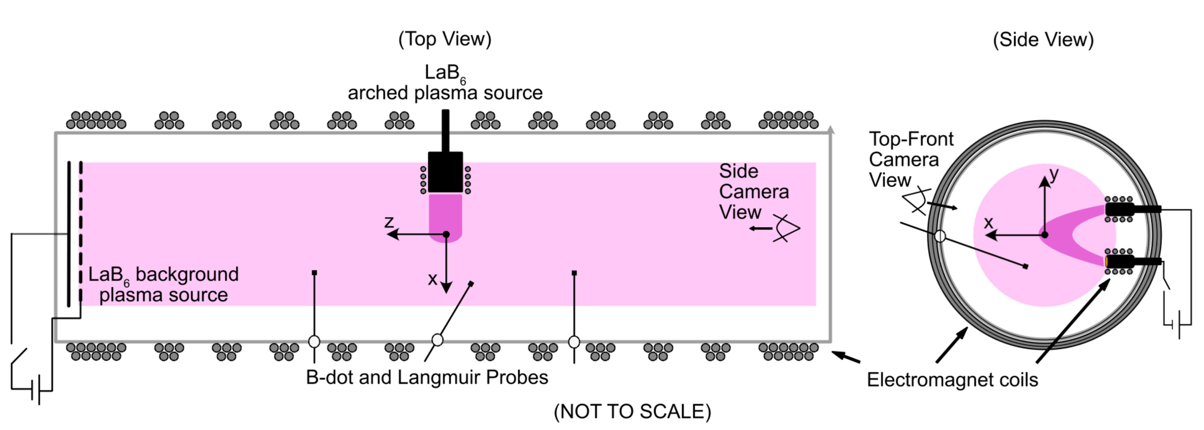


Figure 2: The schematic diagram of the experimental setup.

The arched plasma evolves on timescales faster than a resistive diffusion time
- Resistive diffusion time ≈ 500 µs
- Alfvén transit time ≈ 2 µs
- The early stages of plasma evolution are very dynamic and eruptive (t<50 µs)
- Post eruptive state comes in later during the discharge t>100 µs
- Typical arched plasma current usually lies between 50-150 A.

Diagnostics include:
- B-dot probe (magnetic field)
- Mach probe (flow)
- Langmuir triple probe (density, temperature)
- Fast camera (imaging)

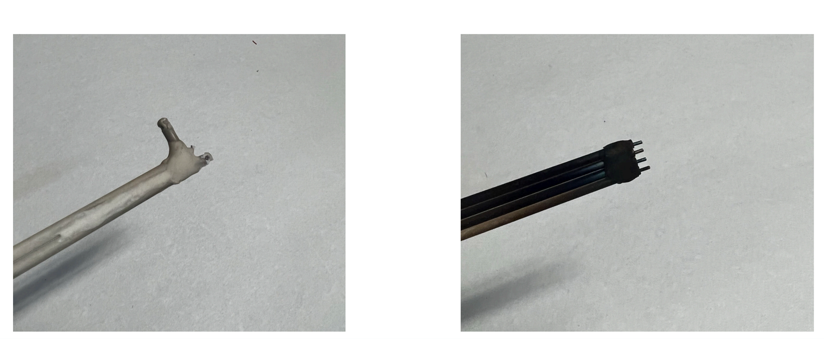
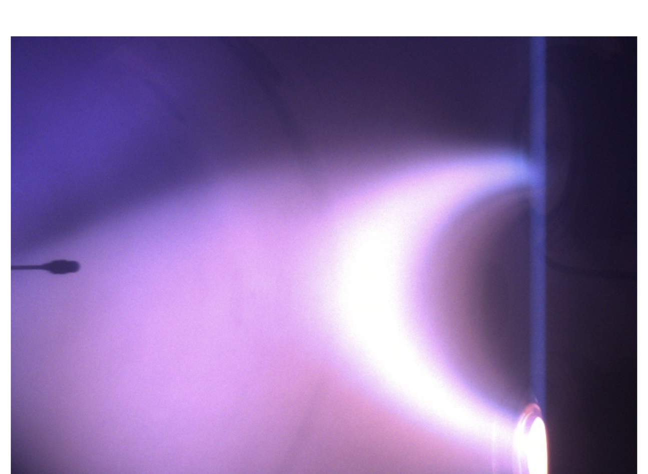


Figure 3: **left:** 3-axis mach probe with local reference tip (tip area ≈ 1mm²) **right:** triple probe with separate tip for V_{float} measurement (tips 2mm long and 0.75mm diameter)



The experiment is highly reproducible and operates at high repetition rate, allowing for the measurement of plasma parameters in three dimension with good spatio-temporal resolution.

Figure 4: Fast camera picture of a typical arched plasma discharge, capturing the b-dot probe during data acquisition.

SIGNATURES OF ERUPTION IN SPACE

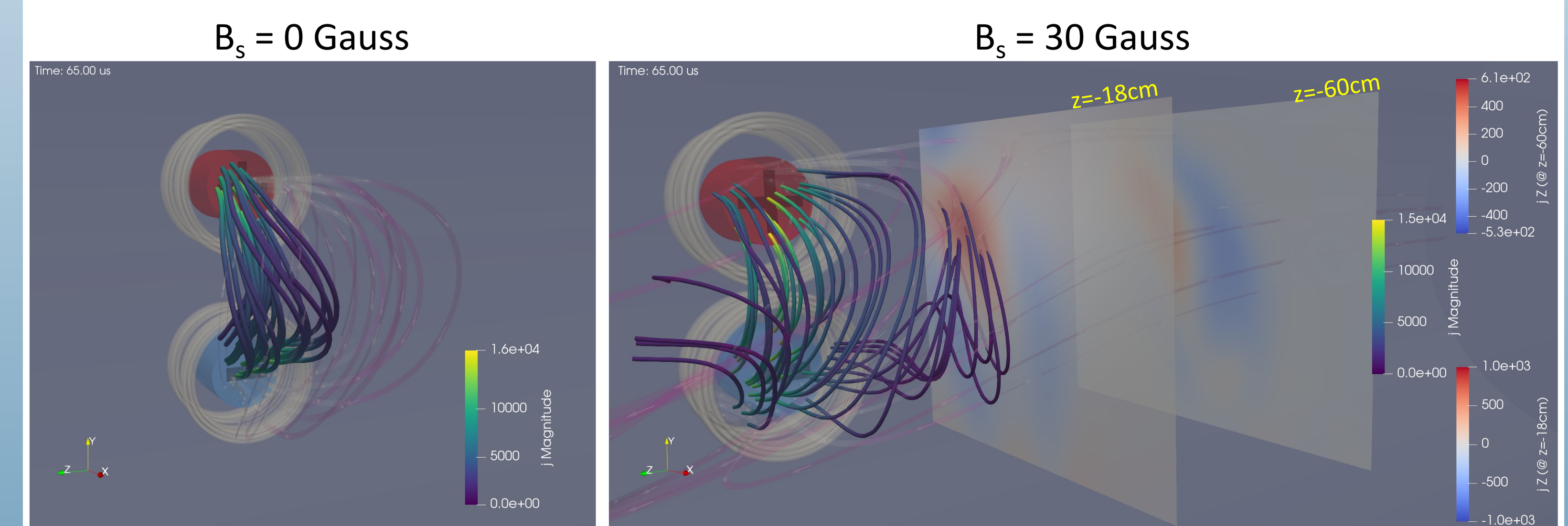


Fig. 5: Three-dimensional rendering of the current density streamlines calculated from the magnetic data collected with b-dot probe (t=65µs after the discharge). The tubular streamlines represent current density, with color scale corresponding to its magnitude. The vacuum. magnetic field is represented by pink ribbons. The two planes on the right panel represent the magnitude of the z-component of current density at z=-18cm and z=-60cm. The presence of strapping field (30 Gauss) leads to an ejection of electric current towards negative z-direction.

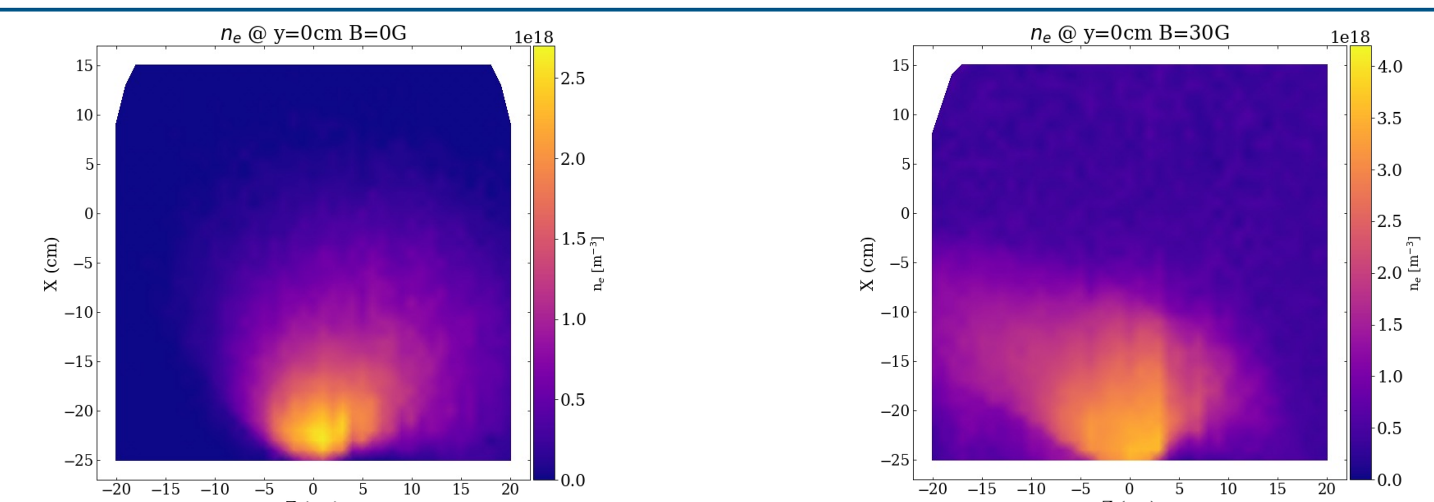


Fig. 6: Electron density at t=48µs after the discharge in the XZ plane at y=0 cm (arch cross section in the middle) for Bs = 0 Gauss on the left and 30 Gauss on the right. There are clear signatures of density towards negative z-axis in the presence of strong strapping field indicating an ongoing eruption.

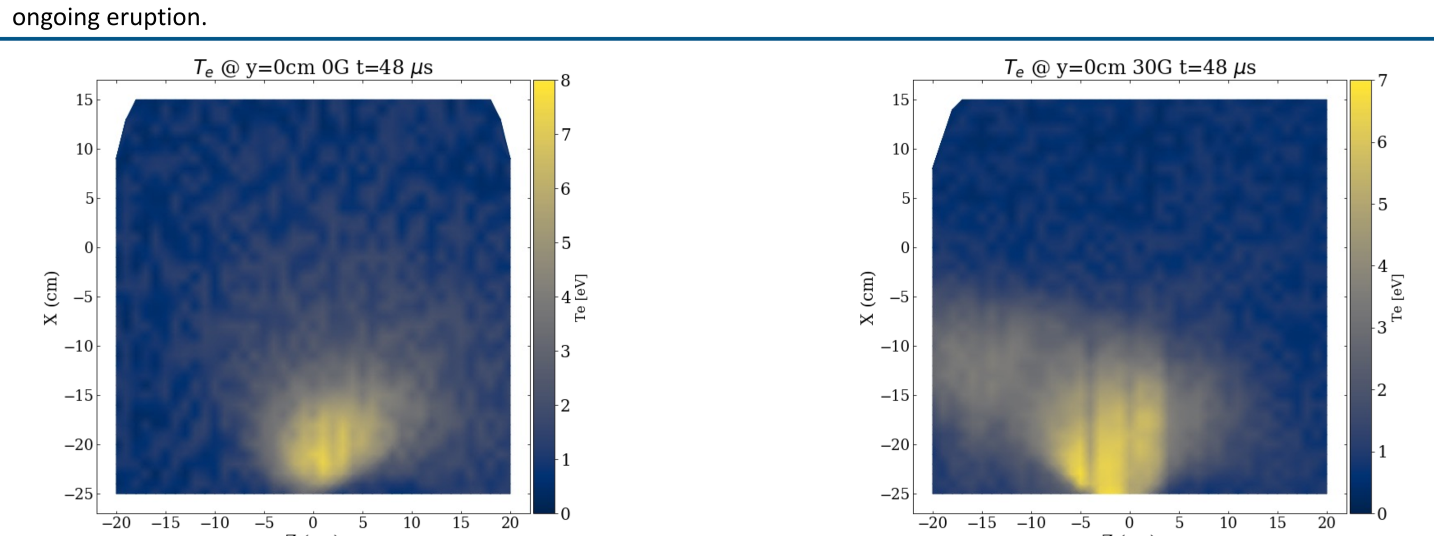


Fig. 7: Electron temperature at t=48µs after the discharge in the XZ plane at y=0 (arch cross section in the middle) for Bs = 0 Gauss on the left and 30 Gauss on the right. The plasma ejected towards negative z-axis (right panel) is evidently energetic.

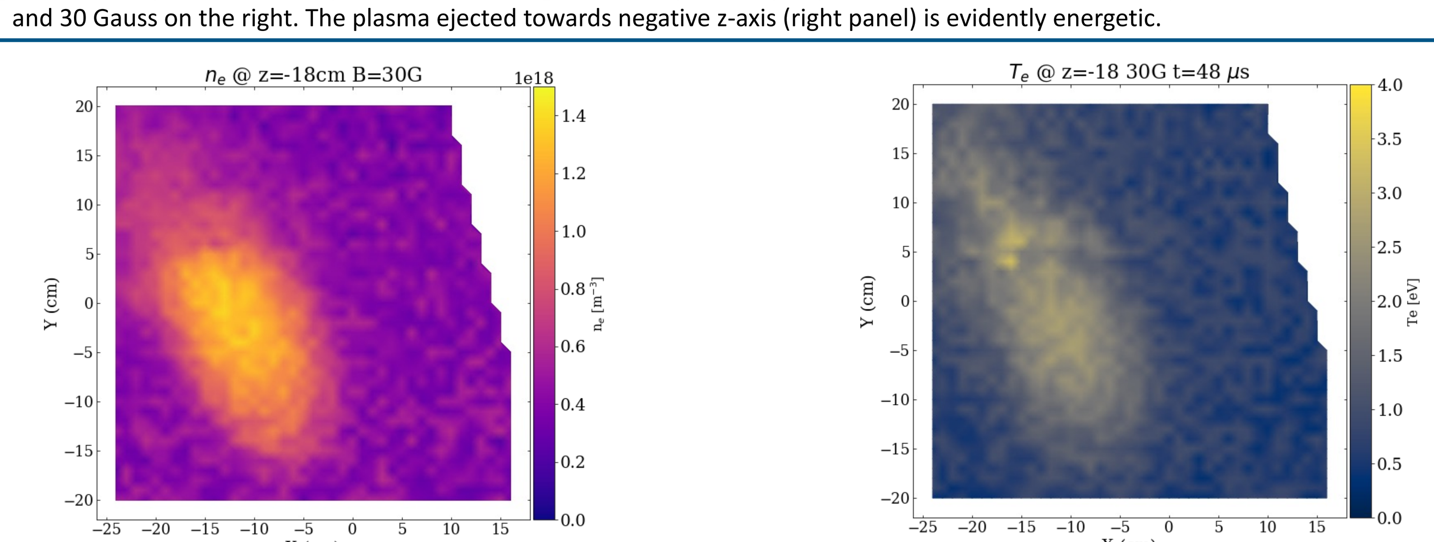


Fig. 8: Electron density (left) and temperature (right) at t=48µs after the discharge in the XY plane at z=-18cm (cross section of the erupted flux rope). With strong magnetic shear present, the energetic plasma is detected beyond the structure of the arch.

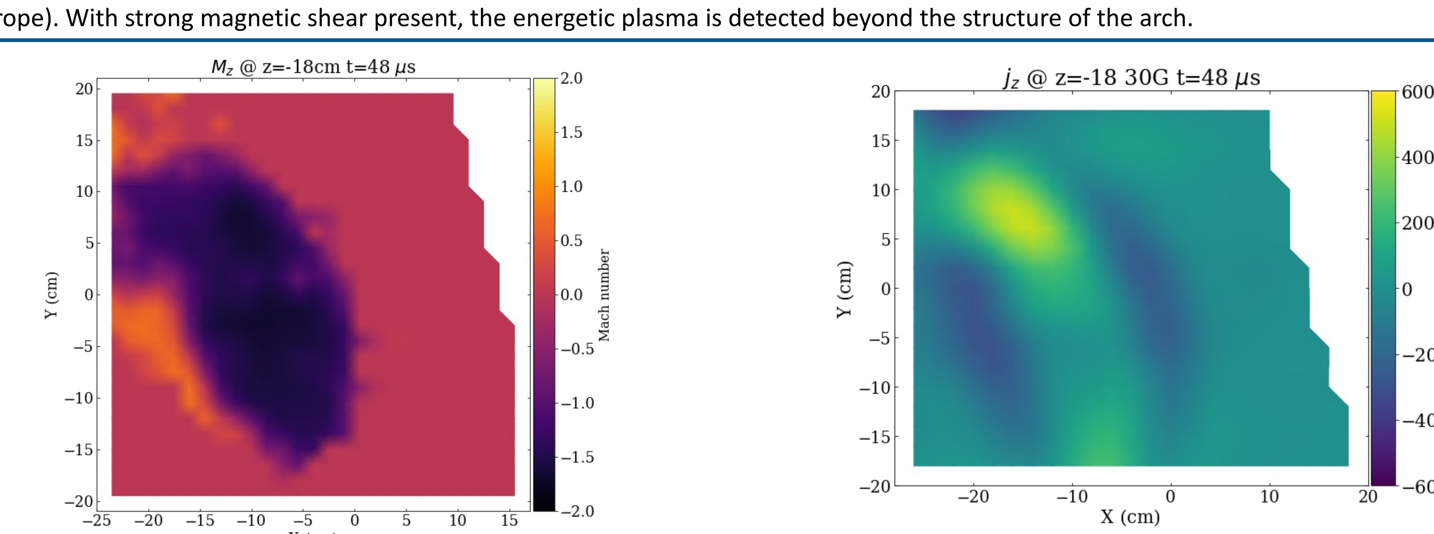


Fig. 9: The z-component of plasma flow (left) and the z-component of current density (right) at t=48µs after the discharge in the XY plane at z=-18cm (cross section of the erupted flux rope). The ejected flux rope carries electric current and a supersonic plasma flow directed away from the arch.

SIGNATURES OF ERUPTION IN TIME

The time traces presented below were generated by averaging the respective data over the area of interest (high signal areas in plots of the center column)

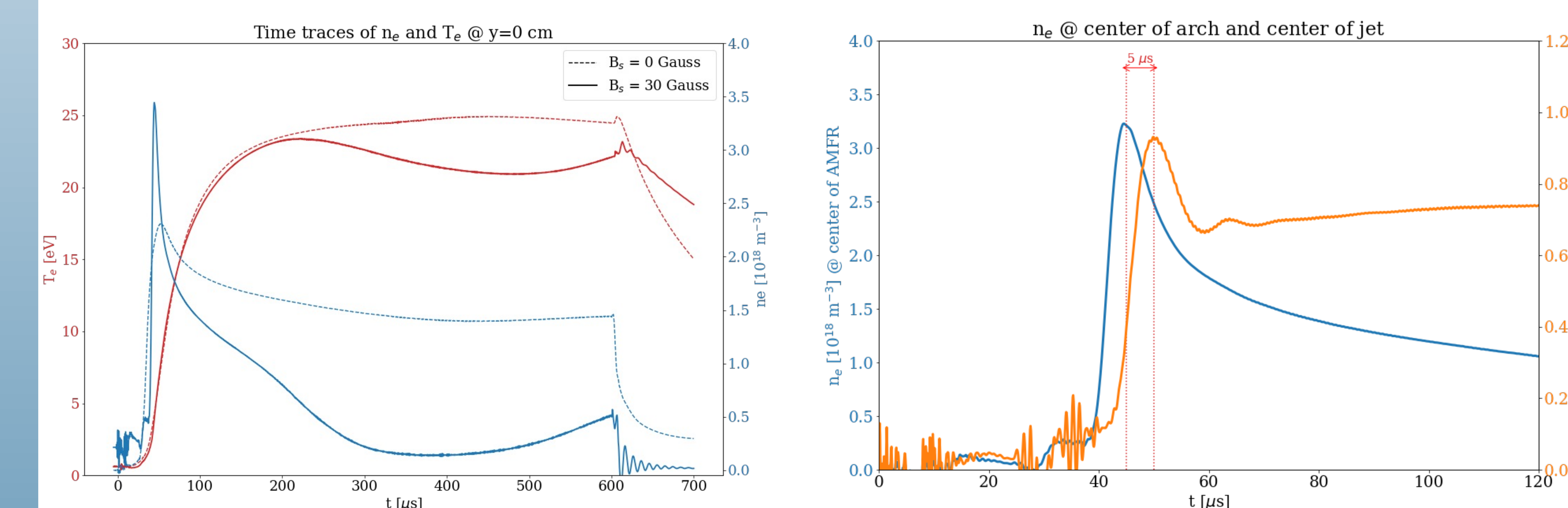


Fig. 10: **(Left)** Time traces for electron density (blue) and temperature (red) at the center area of the arched plasma with strapping field set to 0 Gauss (dashed), and 30 Gauss (solid). There is a strong enhancement in the density during an early onset of the arched plasma evolution when the magnetic shear is present. This suggests an eruptive event during early stages of arched plasma evolution.
(Right) Electron density during early stages of arched plasma evolution in the center of arched plasma (blue) and center of the jet at z=-18cm (orange). The delay between the peaks of those signals is 5 µs. Factoring in the distance plasma had to travel this is equivalent to speed of ≈ 4×10^4 m/s. The ion sound speed for the plasma under study is about 2.5×10^4 m/s. This corresponds to a mach number ≈1.5 which agrees with mach probe measurements (see below).

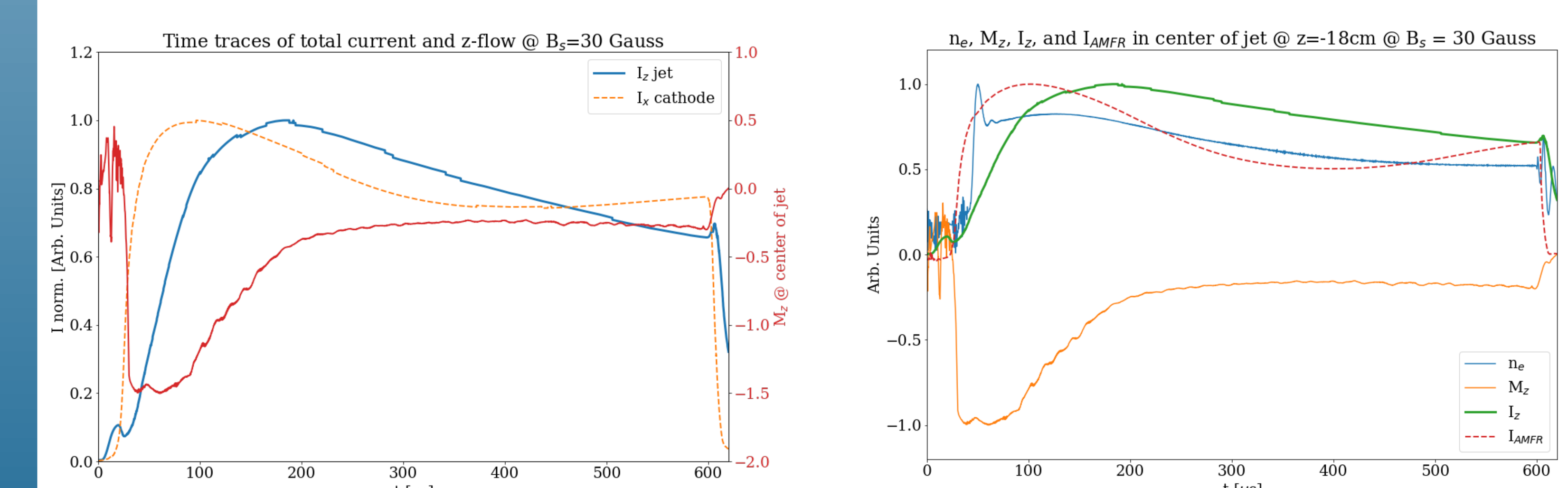


Fig. 11: **(Left)** Time traces of the total current leaving the cathode (dashed orange), the total jet current in z-direction at z=-18cm (blue solid), and the jet z-flow mach number at z=-18cm. The total current lines were obtained by appropriate integration of current density in the area of interest. The mach number trace was obtained by averaging mach probe data over the area of interest. Evidently, the current in the jet develops slower and with delay when compared to the current leaving the cathode, suggesting the jet is a dynamic structure. The flow observed at the location of the jet rises much faster than the respective current, then decays within resistive diffusion timescale (300-500µs). The sharp and transient flow is indicative of an eruptive event.
(Right) Time traces for electron density (blue), the z-component of the flow (orange), the discharge current (dashed red), and the electric current in z-direction (green) in the center of the ejected flux rope. All traces were normalized to own magnitudes. The flow starts sharply with small electric current and small density in the jet region. Plasma flow remains large while electric current and density peak. Finally, all decay within resistive diffusion time scales. The jet is a current-carrying dynamic structure with strong supersonic flow.

JET FLOW STRUCTURE

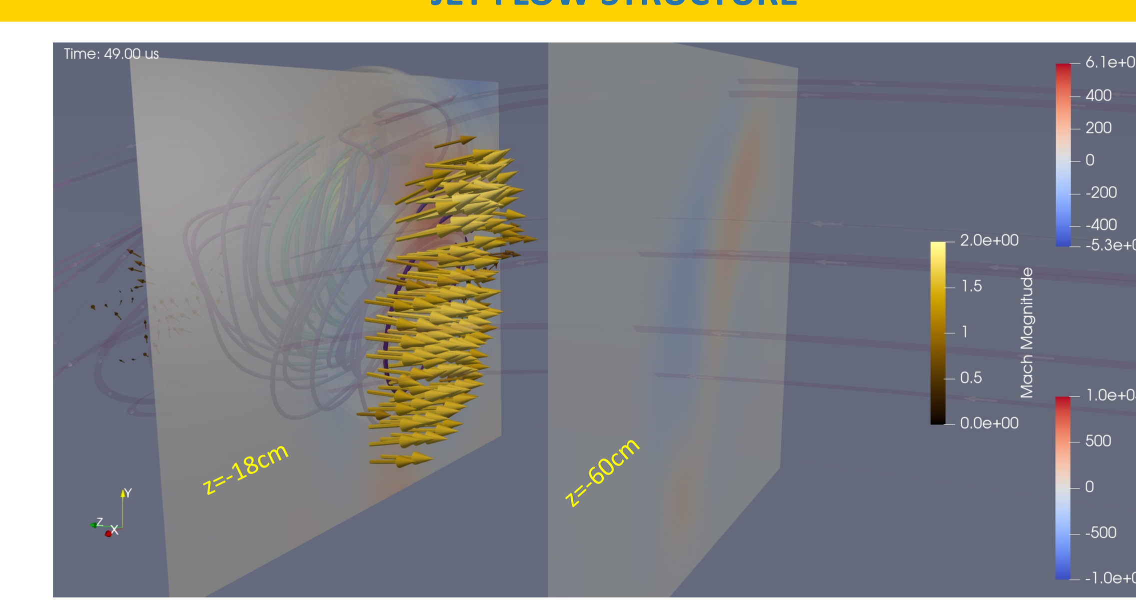


Fig. 12: Three-dimensional rendering of the measured flow vectors at z=-18cm and t= 65µs. The current density streamlines for the arched plasma are visible in the back. The two planes display the magnitudes of j_z at z=-18 and z=-60cm. The vacuum magnetic field is represented by transparent ribbons. Flow has been measured in all three directions, yet most of it is directed along negative z-axis. Plasma is ejected from the arch into the jet at supersonic speeds.

Future Work

- Investigate the role of the magnitude of the magnetic shear on the properties and behavior of the ejected flux rope
- Study the evolution of the arched plasma with variable decay index of the overlying magnetic field (strapping field).
- Investigate the role of magnetic reconnection, Alfvén waves and global oscillations during and after eruptions.

Acknowledgements

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