Experimental Characterization of Magnetogasdynamic Phenomena in Ultra-High Velocity Pulsed Plasma Jets

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Experimental Characterization of Magnetogasdynamic Phenomena in Ultra-High Velocity Pulsed Plasma Jets

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Stanford University

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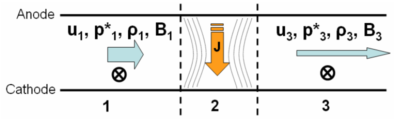
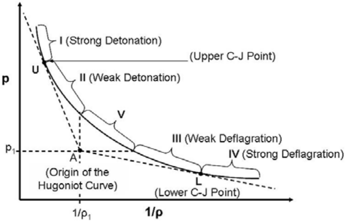
Outline

Background: What is a 'Deflagration'?





- MHD analogy to 1-D combustion waves
- current conduction zone vs. combustion zone
- key features: cooler, less dense products with higher directed kinetic energy
- electromagnetically-accelerated "plasma rocket"

Image 1 from [?].

Motivation

Our goal is to generate hypervelocity neutral plasma jets with known characteristics and to expose materials to these hydromagnetic conditions to produce extreme levels of thermal, physical, chemical, and electrostatic stress.

Desired characteristics:

- > 10 keV ion energy
- > 10 MJ/m^2 energy density
- $> 10^{12}$ W/m^2 peak energy flux

Practical significance:

- match/exceed conditions in edge localized mode disruptions in fusion plasmas
- 1-10 GPa thermo-mechanical stress generated relevant to nuclear stockpile stewardship
- fundamental data on plasma-material interactions under extreme conditions

To advance the goals of the project, we must know:

- plasma density in the jet as a function of position and time
- strength of the local magnetic field convected with the jet
- local velocity of the jet as a function of time

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- **plasma density in the jet as a function of position and time**
- strength of the local magnetic field convected with the jet
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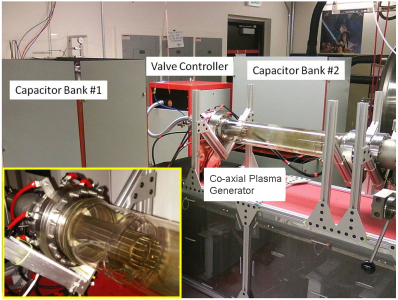
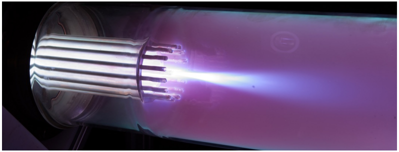
Facility: The Stanford Plasma Gun

Key facility parameters:

- one capacitor bank, 56 μF (expandable to 224 μF)
- pulse energy varied from 60 J - 1.8 kJ (max possible 11.2 kJ)
- charging voltages from 1.5 - 8.0 kV (up to 10 kV possible)
- interelectrode volume 0.001 m^3 (1 L)
- rod/cage anode configuration
- ~500 μg mass bit (Nitrogen)





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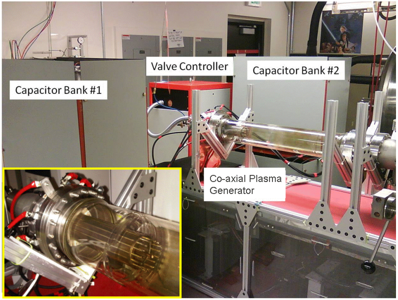

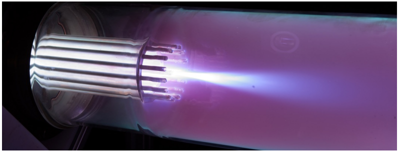

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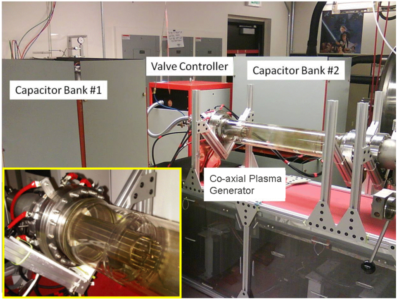

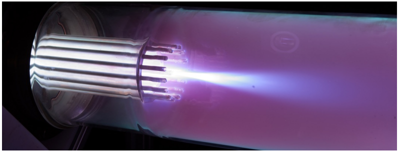

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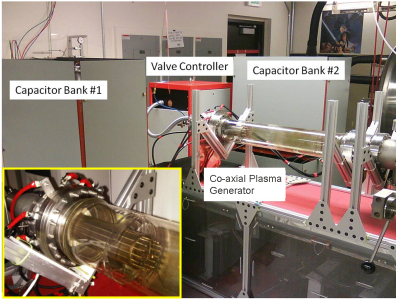

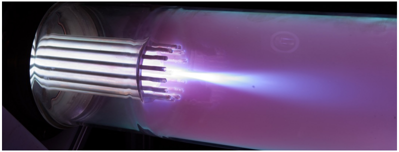

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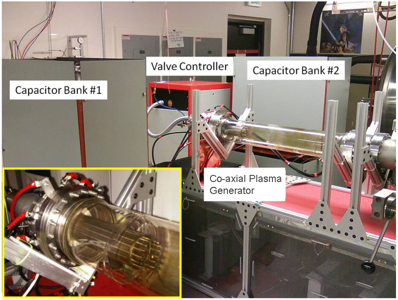

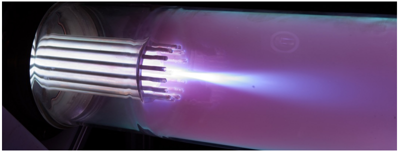

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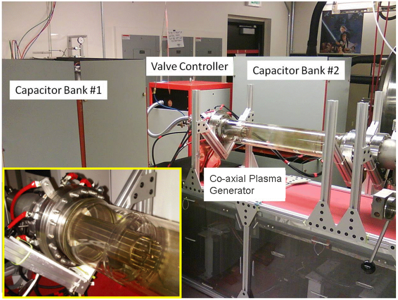
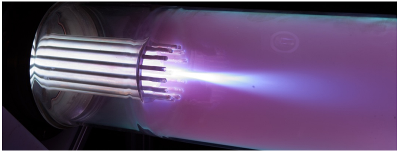
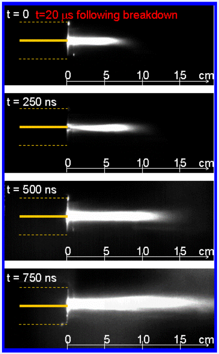




Diagnostics

1. Fast frame rate ICCD camera (Cordin 220)
2. Thomson parabolic energy analyzer (past work)
3. Distributed differentiating Rogowski coils (past work), Pearson current transformer + HV probe
4. Optical frequency interferometer



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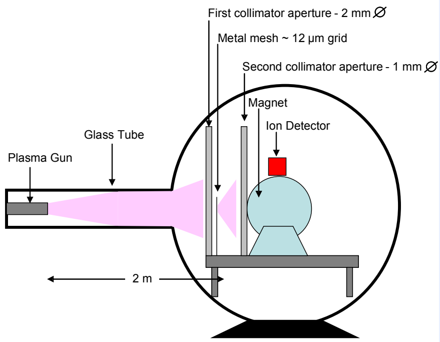

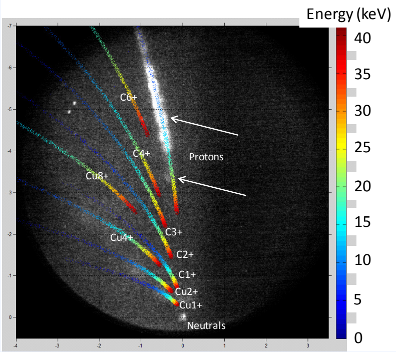

Image 2 from [?].

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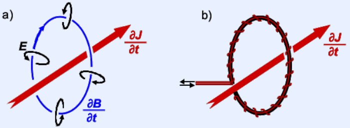

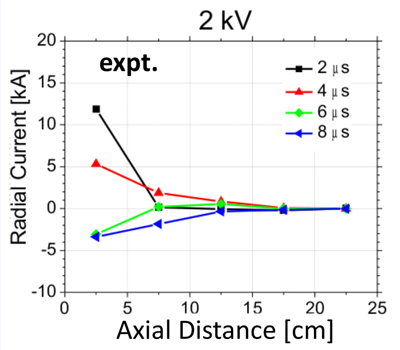

Figs. from [?].

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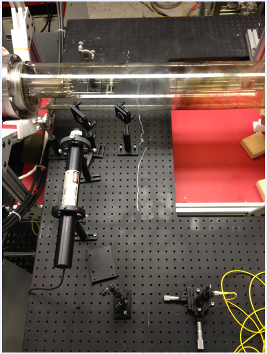
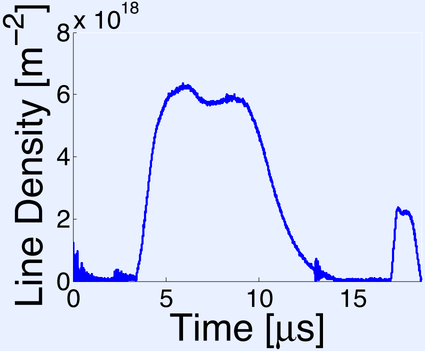
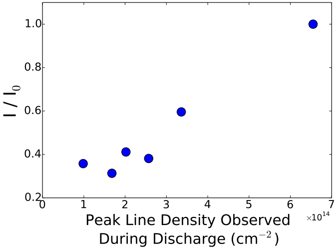


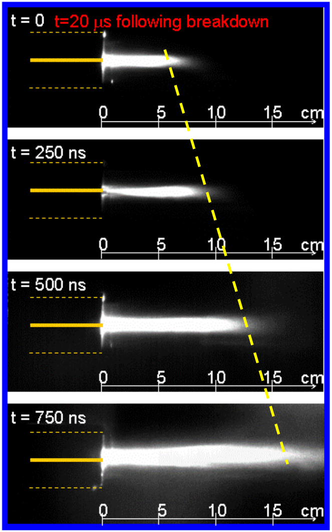


Methodology

Use interferometry information (line density) combined with fast framing ICCD images (velocity, beam diameter, discharge character) to determine parameters of interest.



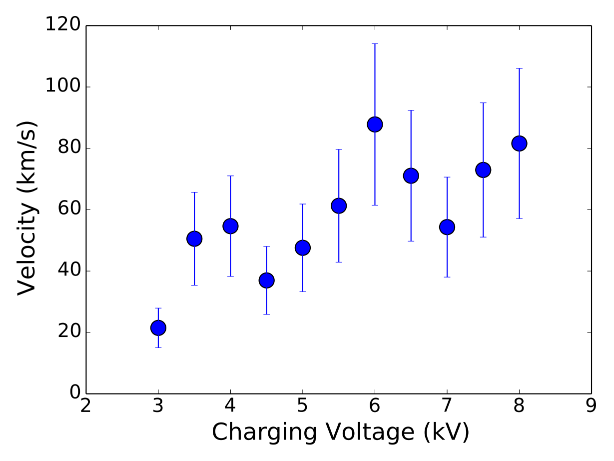
Reprinted from [?].



Experimental Campaign

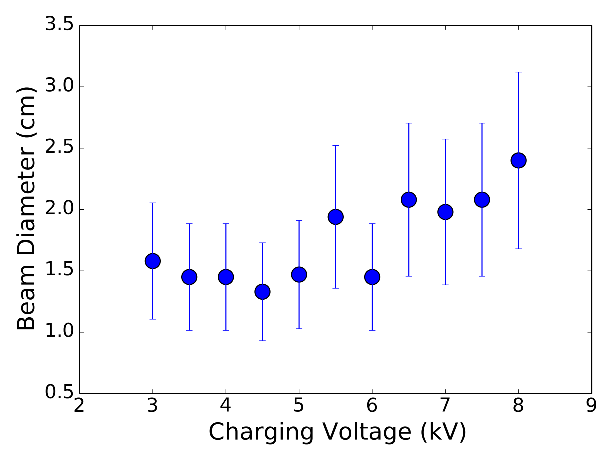
- 11 shots over a range of voltages to obtain TOF velocity
- 15 shots with I and V probes to determine lumped circuit parameters

Jet Parameter Data



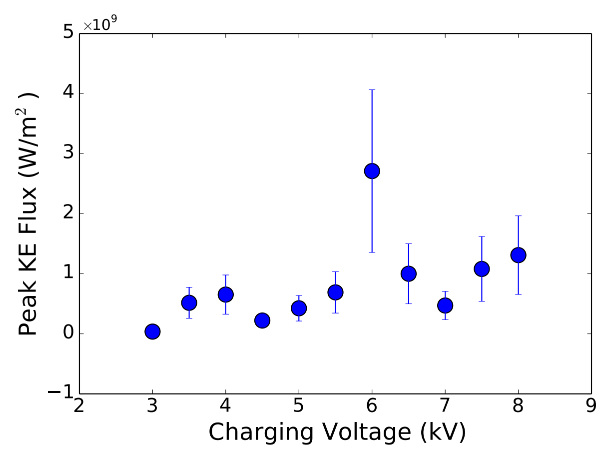
- clear positive correlation with charging voltage

Jet Parameter Data



- increasing beam diameter w/ charging voltage, ∼1.5-2.0 cm

Jet Parameter Data



- energy balance indicates somewhat low (∼5%) efficiency

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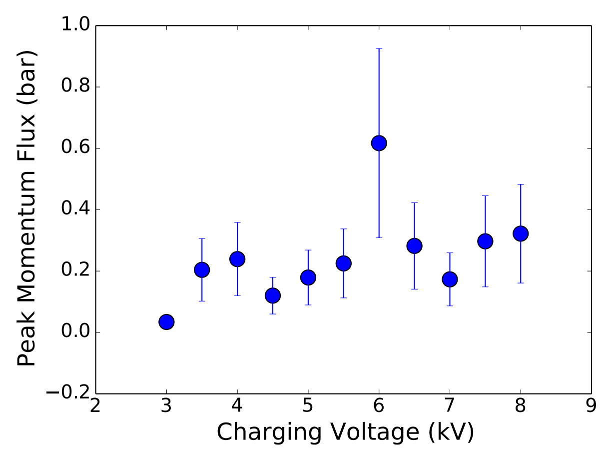
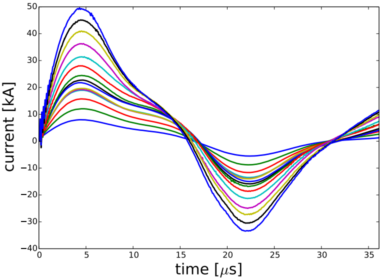
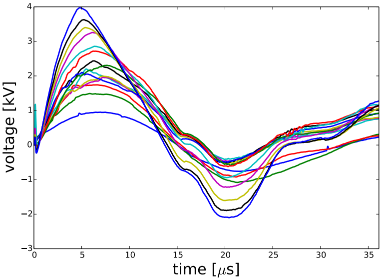


- consistent with the lower energies relative to previous literature

Current and Voltage Traces

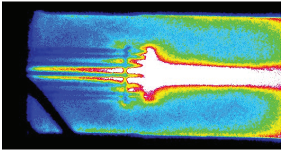




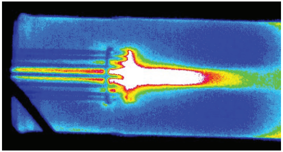
- non-sinusoidal feature during jet expulsion
- waveform scales linearly with charging voltage
- repeatable waveform at similar charging voltage
- 50 kA peak observed at $V_0 = 5.6$ kV

- some likely noise and/or compensation issues
- phase shift vs. current indicates inductive load characteristics
- measurement taken at breach, so voltage drop is both inductive and resistive

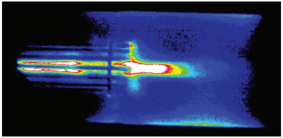
Observed Discharge Features



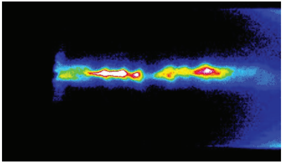
- luminous diameter of beam broadens significantly at exit



- jet continues to expand even as brightest region remains in vicinity of cathode tip

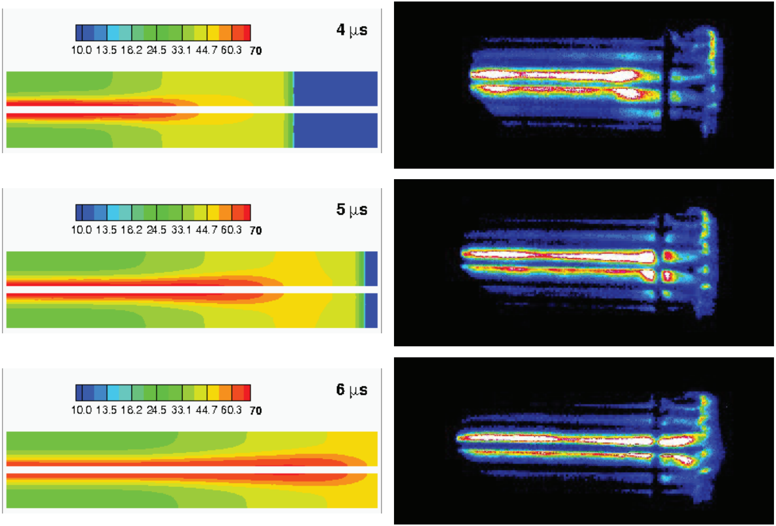


- multiple acceleration events have been observed



- significant jet structure repeatedly captured by ICCD

Qualitative Simulation Benchmarking



Numerical data from [?].

Conclusions

- important preliminary scalings have been established
- deflagration mode of operation in over-fed condition confirmed with ICCD
- external circuit parameters are consistent with the literature
- However: large uncertainties present in underlying data
  - homodyne interferometry, based on smaller mass bit
  - emission time-of-flight velocity measurement → many possible sources of error
  - no quantification of other energy loss mechanisms (thermal, radiative, etc.)

Ongoing and Future Work

- implement sensitive, multi-chord + multi-position heterodyne interferometer to obtain $n_e(r,t)$ and $V(r,t)$ in near-field jet
- adjust I-V probe scheme to mitigate noise/compensation issues
- develop coupled circuit model for comparison with lumped parameters
- implement time-resolved ion temperature diagnostic to capture additional energy dissipation mechanisms
- improve quantification of simulation vs. experiment

Thank You!

Questions?

References