

Michigan Institute for Plasma Science and Engineering (MIPSE)



Proceedings

11th ANNUAL GRADUATE STUDENT SYMPOSIUM

November 17–18, 2020

Virtual

Schedule

Tuesday, November 17, 3:30 - 6:30 pm

- | | |
|-----------------------|---|
| 3:30 - 3:45 pm | Prof. Mark J. Kushner, Director, MIPSE
<i>Opening remarks</i> |
| 3:45 - 4:15 pm | Oral session I (Flashtalk previews of poster sessions I and II) |
| 4:15 - 5:00 pm | Poster session I (separate Zoom meetings for each poster) |
| 5:00 - 5:45 pm | Poster session II (separate Zoom meetings for each poster) |
| 5:45 - 6:30 pm | KLA recruiting activities |

Wednesday, November 18, 3:30 - 7:15 pm

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|-----------------------|--|
| 3:30 - 4:30 pm | Dr. Sarah Nelson, National Nuclear Security Administration
<i>Special MIPSE seminar: Lasers, Z Pinches, and Nuclear Weapons: The Importance of Plasma Physics to the NNSA</i> |
| 4:30 - 5:00 pm | Oral session II (Flashtalk previews of poster sessions III and IV) |
| 5:00 - 5:45 pm | Poster session III (separate Zoom meetings for each poster) |
| 5:45 - 6:30 pm | Poster session IV (separate Zoom meetings for each poster) |
| 6:30 - 7:00 pm | Break |
| 7:00 - 7:15 pm | Best Presentation Award ceremony |

Poster Session I

Tuesday, November 17, 4:15 - 5:00 pm

1-01 Asif Iqbal (MSU)

(p. 8) *Characterization of Single Surface Multipactor Discharge in the Frequency Domain*

~~1-02~~ Moved to Poster Session II

1-03 Jinyu Yang (ND)

(p. 9) *Characterization of Single Surface Multipactor Discharge in the Frequency Domain Hand-generated Piezoelectric Mechanical-to-electrical Energy Conversion Plasma*

1-04 Michael Springstead (U-M)

(p. 10) *Characterization of Single Surface Multipactor Discharge in the Frequency Domain Laboratory Generated Photoionization Fronts Relevant to Cosmology*

1-05 Austin Brenner (U-M)

(p. 11) *Characterization of Single Surface Multipactor Discharge in the Frequency Domain Modeling the Earth's Magnetosphere as a Current Circuit*

1-06 Jordyn Polito (U-M)

(p. 12) *A Global Model for the Atmospheric Pressure Plasma Surface Functionalization of Polystyrene*

1-07 Kwyntero Kelso (U-M)

(p. 13) *Observation of Photoionization Fronts in Laboratory Experiments*

1-08 Joshua Woods (U-M)

(p. 14) *Pathways for Increased Performance of a Rotating Magnetic Field Thruster*

1-09 Yang Zhou (MSU)

(p. 15) *Plasmon-Enhanced Resonant Photoemission Using Atomically Thick Dielectric Coatings*

1-10 Zachariah Brown (U-M)

(p. 16) *Experimental Measurement of Non-linear Coupling and Energy Transfer in Plasma Turbulence in a Hall Effect Thruster*

1-11 Michael Wadas (U-M)

(p. 17) *A Theoretical Approach for Transient Shock Strengthening in High-energy-density Laser Compression Experiments*

Poster Session II

Tuesday, November 17, 5:00 - 5:45 pm

1-02 Julian Kinney (U-M)

(p. 19) Exploration of Parameters for a Future Radiative Shock/Shear Experiment

2-01 Yi Luo (MSU)

(p. 20) Exact Theory for Pulsed Laser Induced Photoemission from Biased Surface

2-02 Griffin Cearley (U-M)

(p. 21) Computational Investigation of Impulse-fluence Scaling in X-ray Illuminated Materials on the National Ignition Facility

2-03 Tate Gill (U-M)

(p. 22) Design of a Three-phase Rotating Magnetic Field Power Processing Unit for Inductive Plasmoid Propulsion

2-04 Daniel Martin (ND)

(p. 23) Experimental Confirmation of Transport Model for Solvated Electrons in a Plasma Electrochemical System

2-05 Ryan Sandberg (U-M)

(p. 24) FARRSIGHT: A Forward Adaptively Refined and Regularized Semi-Lagrangian Integral Green's Function Hierarchical Tree-code Accelerated Method for the Vlasov-Poisson System

2-06 Hongmei Tang (U-M)

(p. 25) High Energy, Relativistic Intensity Laser Channeling and Direct Laser Acceleration of Electrons from an Underdense Plasma

2-07 Mackenzie Meyer (U-M)

(p. 26) Modeling Sheath Dynamics around Water Droplets in Low Temperature Plasmas

2-08 Lucas Stanek (MSU)

(p. 27) Multi-Fidelity Machine Learning for Extending the Range of High-Fidelity Molecular Dynamics Data

2-09 Benjamin Wachs (U-M)

(p. 28) Optimization of a Low Power ECR Thruster using Two-Frequency Heating

2-10 Mario Balcazar (U-M)

(p. 29) Phase-Contrast Imaging of Hydrodynamic Shocks in Water with a Betatron X-ray Source

2-11 Connor Todd (U-M)

(p. 30) Production of Synthetic Phase Contrast Images for Comparison with CRASH Radiograph Output

2-12 Andre Antoine (U-M)

(p. 31) Using Reduced Order Modeling to Understand the Physics of Injection in Laser Wakefield Acceleration

Poster Session III

Wednesday, November 18, 5:00 - 5:45 pm

3-01 Forrest Glines (MSU)

(p. 33) *Decaying Magnetized Turbulence in the Taylor-Green Vortex*

3-02 Abhijit Jassem (U-M)

(p. 34) *Analysis of Miram Curves with Two-Dimensional Work Function Distributions*

3-03 Sneha Banerjee (MSU)

(p. 35) *Contact Engineering in 2D-Material-Based Electrical Contacts*

3-04 Akash Shah (U-M)

(p. 36) *Development of a Gas-Puff Z-Pinch Experiment for the 1-MA, 100-ns MAIZE Linear Transformer Driver*

3-05 Milad Rasouli (Kharazmi University)

(p. 37) *Gas Plasma Effects on Chemoresistance Ovarian Cells*

3-06 Kseniia Konina (U-M)

(p. 38) *Interactions of Porous Dielectric Materials with Atmospheric Pressure Plasmas*

3-07 Brandon Russell (U-M)

(p. 39) *Magnetic Field Generation at Extreme Laser Intensities*

3-08 George Dowhan (U-M)

(p. 40) *New X-Pinch Platform and Diagnostics for the MAIZE Facility*

3-09 Jon Murphy (U-M)

(p. 41) *Optimization of High Repetition-rate Laser-driven Particle and Radiation Sources Using Machine-learning Techniques*

3-10 Leanne Su (U-M)

(p. 42) *Physical Differences Between Xenon and Krypton Operation on a Magnetically-Shielded Hall Thruster*

3-11 Jinpu Lin (U-M)

(p. 43) *Towards Predicting Electron Beam Charge upon Phase Control in Laser Wakefield Accelerators Using Supervised Learning Techniques*

3-12 Thomas Marks (U-M)

(p. 44) *Fluid Simulations of Magnetic Nozzle Thruster Including Plasma Source*

Poster Session IV

Wednesday, November 18, 5:45 - 6:30 pm

4-01 Janez Krek (MSU)

(p. 46) *Utilizing a Global Model to Identify Relevant Reactions in Chemically Complicated Plasma Systems*

4-02 Raul Melean (U-M)

(p. 47) *Characterization of Pulsed-power Magnetized Jets on MAIZE*

4-03 Steven Lanham (U-M)

(p. 48) *Controlling Composition of Particles Grown in Dusty Plasmas*

4-04 Christopher Sercel (U-M)

(p. 49) *Effect of Flux Conservers on Inductive Pulsed Plasmoid Thrusters*

4-05 Robert VanDervort (U-M)

(p. 50) *Experiments Relevant to the Interaction of Stellar Radiation with Nearby Gas Clouds*

4-06 Matthew Byrne (U-M)

(p. 51) *Investigation of Techniques to Mitigate the Erosion of a Mesh Reflector Exposed to a Hall Thruster Plume*

4-07 Shadrach Hepner (U-M)

(p. 52) *Low Frequency Instabilities in a Magnetic Nozzle*

4-08 Heath LeFevre (U-M)

(p. 53) *Ni-lined Capsules as Backlighters for Multiple Measurements in High-energy-density Physics Experiments*

4-09 Jason Cardarelli (U-M)

(p. 54) *Optimized Spectroscopic Measurement of High Energy, Narrow Energy-Spread Electron Beams from a Laser Wakefield Accelerator*

4-10 Khalil Bryant (U-M)

(p. 55) *PlasmaPy for HEDP Regime*

4-11 Collin Whittaker (U-M)

(p. 56) *Uncertainty Quantification and Credible Predictions for Reduced-Fidelity Modeling of Porous Electro spray*

4-12 Shannon Hill (U-M)

(p. 57) *Using Auroras to Investigate the Geospace Magnetic Topology*

Abstracts
Poster Session III

Characterization of Single Surface Multipactor Discharge in the Frequency Domain*

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This work presents the characterization of the single surface multipactor discharge [1] in the frequency domain with rf electric fields of single or two carrier frequencies. We employ a multiparticle Monte Carlo (MC) simulation scheme [2] in one dimension with exact adaptive time steps to obtain the temporal profiles of the normal electric field to the dielectric surface [3]. We perform Discrete Fourier Transform (DFT) on the temporal profile and obtain the amplitude spectrum of the normal electric fields in the ac saturation state. The normal electric field corresponds to the multipactor strength in the system.

For single frequency rf operation, we observe [4] spectral peaks in the amplitude spectrum of the normal electric field, E_x , at the even harmonics of the fundamental rf frequency (Fig. 1a). We express the heights of the spectral peaks as functions of their respective harmonic numbers and the rf amplitude. We find empirical expressions to describe the temporal profile of the normal electric field in terms of the DFT peaks (Fig. 1b).

For two-frequency rf operation, spectral peaks are observed at various frequencies of intermodulation products [4] of the two carrier frequencies (Fig. 1c). The temporal profile of the normal electric field can be approximated by an empirical equation in terms of these most prominent spectral peaks (Fig. 1d).

*Work supported by AFOSR MURI Grant No. FA9550-18-1-0062, and MIPSE Graduate Fellowship.

References

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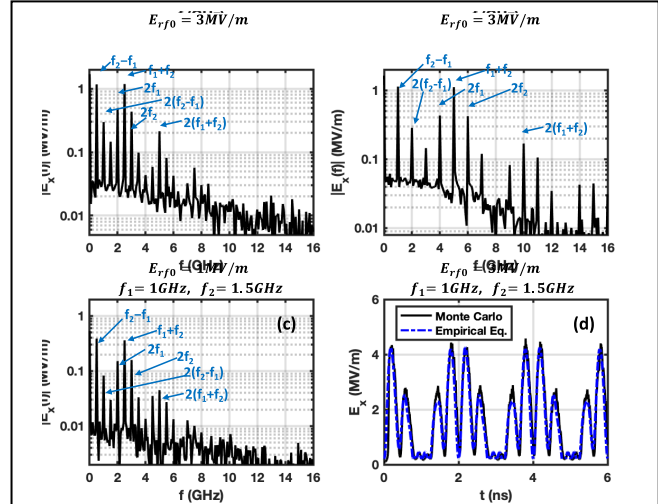


Figure 1 – Top row: (a) Amplitude spectrum of the normal electric field in the ac saturation state for single carrier rf operation with rf amplitude, $E_{rf0} = 3\text{MV/m}$ and frequency $f_{rf} = 1\text{GHz}$, (b) Temporal profiles of the normal electric field E_x in the ac saturation state for the rf configuration in (a) obtained from the MC simulation (black solid lines) and the proposed empirical equation (blue dashed lines). Bottom row: (c-d) Same plots as (a-b) for two-frequency rf operation with rf amplitude $E_{rf0} = 3\text{MV/m}$ and frequencies $f_1 = 1\text{GHz}$, $f_2 = 1.5\text{GHz}$.

Hand-generated Piezoelectric Mechanical-to-electrical Energy Conversion Plasma*

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This work examines electrical characteristics of the transient spark generated by a manually-powered piezoelectric mechanical-to-electrical energy conversion device. The transient spark is a streamer-to-spark transition discharge at atmospheric pressure that has potentials in pollutant removal, medicine, water treatment, nanomaterial synthesis, combustion, and flow control. Conventional methods to generate transient sparks usually require a high-voltage input at nanosecond pulses. Piezoelectric crystals offer a path to create plasma devices that do not require a high-voltage power supply and can be powered with mechanical work. Here, a piezoelectric igniter was utilized as the plasma source, and a snail cam-and-follower actuator was designed to provide repeatable mechanical actuation. Electrical analysis of the generated discharge shows that it behaves as a transient spark, discharging 0.96 mJ over approximately 30 ns, with consistent behavior over multiple consecutive actuations. While this specific device has a low mechanical-to-plasma energy conversion efficiency of 1.54%, its relatively short resetting time of $\sim 8 \mu\text{s}$ suggests that it could be operated with mechanical input up to nearly 125 kHz. This work with a manually-powered piezoelectric plasma device shows the potential that *in situ* pollution mitigation or plasma-enhanced combustion can be applied to off-the-grid situations by recovering waste energy of other mechanical systems. Greater promise can be achieved with mechanical systems that naturally operate at frequencies similar to the maximum achievable by this piezoelectric system, such as the high-frequency oscillating or rotating components of internal combustion engines and turbomachinery.

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Laboratory Generated Photoionization Fronts Relevant to Cosmology*

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Photoionization Fronts (commonly referred to as Ionization Fronts or PI fronts) are a type of radiation-driven heat front that dictate important physics in reionization era of the early universe. The first galaxies of the reionization era merged to form minihalos. Subsequently, these minihalos emitted ionizing radiation to the surrounding gas clouds, which generated PI fronts. The asymmetric propagation and attenuation of a PI front within a gas cloud is an active area of study in the early universe cosmology. In the laboratory setting, the Z Astrophysical Plasma Properties (ZAPP) platform on Sandia's Z-Machine facility is capable of generating an intense radiation source to drive a PI front through a 0.75atm nitrogen gas cell. To better understand upcoming ZAPP experiments on Sandia's Z-Machine, this work presents an initial experimental design, accompanied by HELIOS radiation-hydrodynamic simulations, and PrismSPECT atomic kinetics calculations.

* This work is funded by the U.S. Department of Energy NNSA Center of Excellence under cooperative agreement number DE-NA0003869.

Modeling the Earth's Magnetosphere as a Current Circuit

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WINDMI is a low dimensional model that represents the space environment around earth as an electrical circuit as shown in figure 1 and can be used as a prediction tool via the outputs of the region 1 current and ring current values which correlate to geomagnetic indices of Auroral Electro-jet (AL) and Disturbance Storm Time (Dst) respectively. This model approximates the plasma in geospace regions as circuit elements that store or transform electromagnetic energy. This work investigates the circuit component approximations of several of the WINDMI model elements by comparing to high fidelity 2-way coupled MHD simulation, the Space Weather Modeling Framework (SWMF)[2].

A two day event of February 18-19 2014 is simulated using both SWMF and WINDMI. Python is used along with Tecplot 3D visualization software to identify the appropriate spatial re-gions and integrate field data output from SWMF to make one-to-one comparisons of power and energy quantities over time with the WINDMI circuit elements. By making direct comparisons it can be seen where low dimensional approximations can accurately capture the plasma dynamics and where these approximations fall short.

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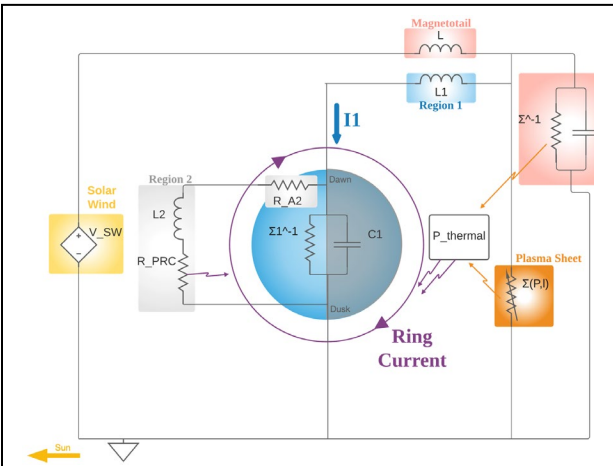


Figure 1 - WINDMI circuit representation.

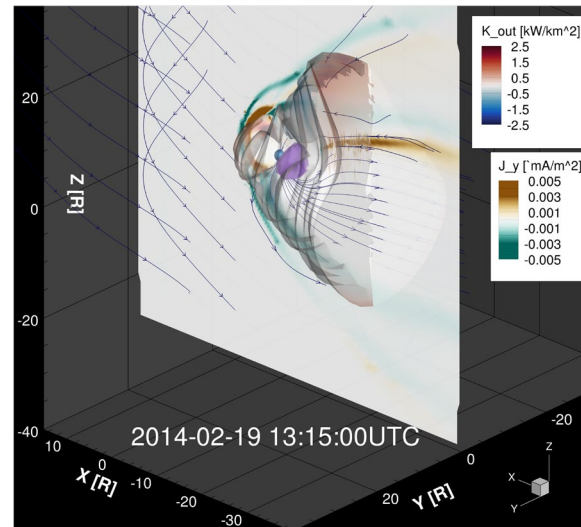


Figure 2 - SWMF 3D Magnetopause with energy flux and mid-plane current densities.

A Global Model for the Atmospheric Pressure Plasma Surface Functionalization of Polystyrene*

Jordyn Polito ^a, Mark J. Kushner ^b, Mark Denning ^c, David Frost ^c and Richard Stewart ^c

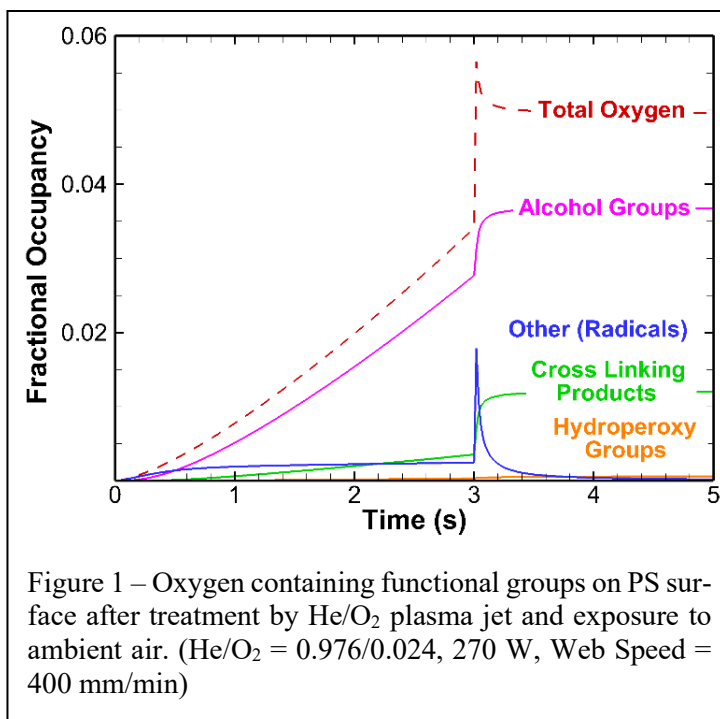
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Atmospheric plasma surface treatment is commonly used in industry to improve adhesion and wettability of bulk commodity polymers, such as polypropylene (PP), polyethylene, and polystyrene (PS) for uses in biomaterials and biomedical devices [1]. Treatment of polymers by plasmas involves the abstraction of H from the polymer backbone by O atoms or OH radicals to form alkyl radicals on the PS surface. O₂ can then be fixed to the alkyl sites to lower surface energy, resulting in increased wettability and adhesive properties. Correlating plasma operating conditions with fractional surface coverage of O-containing groups would help be valuable for process design of plasma functionalization systems.

In this work we computationally investigate surface functionalization of PS using He/O₂ plasma jets. GlobalKin, a 0-dimensional global plasma chemistry model was used to simulate an RF driven plasma jet exiting into room air onto a PS surface situated a few mm from the reactor outlet. A surface site balance module [2] was used to predict fractional occupancy of oxygen on the PS surface after treatment due to gas phase-surface and surface-surface reactions. Results for trends in the fractional coverage by O-containing functional groups as functions of power, oxygen inlet fraction, web speed, relative humidity of room air, and PS distance from the nozzle after exposure to ambient air will be discussed. Results from the model will be validated by comparison to experimental trends for water contact angle measurements.



* This work was supported by Agilent Technologies and the Department of Energy Office of Fusion Energy Science

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Observation of Photoionization Fronts in Laboratory Experiments*

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Photoionization fronts are meaningful drivers of transformation for astrophysical phenomena and remain difficult to produce in laboratory experiments. As the universe evolved, the first dense structures were galaxies made mostly of dark matter which lead to sustained ionizing radiation, starting the reionization epoch. When minihalos cooled atomically, populations of stars emerged creating photoionization fronts forming these galaxies. Experiments at the OMEGA Laser Facility can create relevant photoionization conditions. One can generate an X-ray source with radiation temperature of about 90eV that irradiates a nitrogen medium held at high pressures. A laser irradiated gold foil generates an X-ray source which propagate deeper into a nitrogen gas cell. Measuring the temperature, density, and ionization state of the heated region yields ratios for the calculation of atomic rate coefficients.

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Pathways for Increased Performance of a Rotating Magnetic Field Thruster

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The design of a rotating magnetic field (RMF) thruster is presented. RMF thrusters are a type of inductive pulsed propulsion device. It utilizes a rotating magnetic field to produce an azimuthal current in the presence of a steady background field with a radial gradient to eject plasma at high velocity and repetition rates [1]. Historically, performance of RMF thrusters has been low. The highest observed efficiency is 8% [2]. To better understand the device, the University of Michigan's Plasmadynamics and Electric Propulsion Laboratory (PEPL) developed an RMF test article capable of operating over a number of conditions. The thruster was tested at power levels lower than 1 kW. There was little to no thrust measured and coupling efficiency was less than 5% for all cases [3].

In an effort to increase the thrust and efficiency, PEPL has designed an advanced test article that leverages lessons learned from previous experimental campaigns as well as recent analytical models indicating how to better optimize the thruster [3,4]. Notably, the thruster casing has been switched from a conductive aluminum assembly to a nonconductive G10 one. This reduces losses due to the magnetic fields coupling to structural materials instead of the plasma. Further, a plasma baffle has been installed downstream of the pre-ionizer hollow cathode to help diffuse the neutral gas and plasma towards the RMF antennae. Finally, the thruster will be operated at power levels in excess of 5 kW. It is theorized that higher coil currents will significantly increase the coupling between the RMF coils and plasma. These design changes will ideally lead to increased overall thruster performance compared to previous designs.

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Plasmon-Enhanced Resonant Photoemission Using Atomically Thick Dielectric Coatings*

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Photoemission from nano-emitters is crucial for many applications, such as compact radiation sources, particle accelerators, ultrafast electron microscopy, carrier-envelope detection, and novel nano-electronic devices, for its high brightness, low emittance, extreme spatiotemporal resolution, and carrier-envelope sensitivity [1-2]. The quantum efficiency of photoemission from nanostructured emitters can be significantly improved due to the increase of the local optical fields from the geometrical field enhancement and surface plasmon resonances.

In this study, we propose to coat the metal nano-emitters with an atomically thick dielectric to further enhance the laser field near the nanotips. The full-wave optical simulation demonstrates an optical field enhancement factor of up to 400 [4], depending on the geometry of the nano-emitter and resonance wavelengths. The physics behind this lies in the secondary field enhancement of the plasmonic field in the coating layer beyond the geometrical plasmon field enhancement effects. A quantum photoemission model, which is constructed by solving the time-dependent Schrödinger equation exactly [2-4], is utilized to investigate the photoemission processes. It is found that, over a wide range of laser fields, the emission current density from the coated photoemitter is enhanced by at least 2 orders of magnitude as compared to the bare emitter (Fig. 1). The effects of the coating properties such as refractive index and thickness, and geometrical settings are studied, and tunable photoemission is numerically demonstrated using different lasers and emitter geometries. The current density from different geometrical nanopyramid emitters (corresponding to different resonance wavelengths) shows that the optical field tunneling occurs at an ultralow incident laser field of 0.03 V/nm [4].

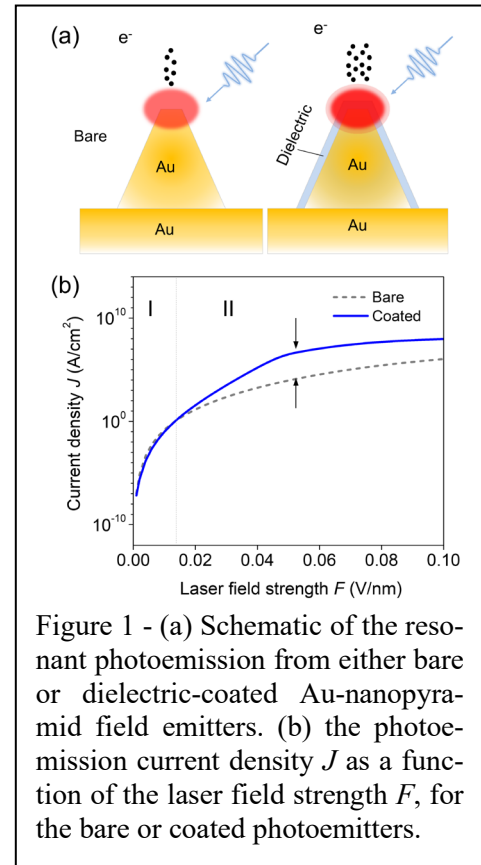


Figure 1 - (a) Schematic of the resonant photoemission from either bare or dielectric-coated Au-nanopyramid field emitters. (b) the photoemission current density J as a function of the laser field strength F , for the bare or coated photoemitters.

* Work supported by AFOSR YIP Award (No. FA9550-18-1-0061), ONR YIP Grant No. N00014-20-1-2681, the National Research Foundation Singapore NRF2017-NRF-NSFC002-015 and A*STAR SERC A1685b0005.

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Experimental Measurement of Non-linear Coupling and Energy Transfer in Plasma Turbulence in a Hall Effect Thruster*

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Hall thrusters are a form of crossed-field plasma device commonly employed for in-space electric propulsion. A strong magnetic field confines the lighter species of the plasma, electrons, which ionize the propellant, while an applied electric field accelerates the ions downstream. Ideally, the electrons would be confined by the magnetic field, serving as an efficient ionization source. However, it has been found experimentally that electrons can cross field lines in these devices at rates orders of magnitude higher than can be explained by classical collision effects.

To date, no self-consistent model has been developed for this anomalous electron transport. This lack of understanding about Hall thruster plasma dynamics precludes predictive modelling and forces designs to be validated with lengthy and expensive physical testing. The prevailing theory to explain anomalous electron transport supposes that a strong azimuthal plasma instability develops in the Hall thruster that can knock electrons across magnetic field lines. The instability is known as the $E \times B$ electron drift instability (EDI), due to the plasma turbulence gaining energy from the electrons' high $E \times B$ drift velocity [1].

Recent particle-in-cell simulations have demonstrated that this wave driven transport is strongest due to oscillations at long wavelengths that develop from a non-linear energy cascade from the initial, small wavelengths [2]. Using the analysis technique of Ritz [3], we experimentally show that this theorized non-linear effect does occur in these devices. Furthermore, these non-linear effects dominate the linear mechanisms in regards to the spatial evolution of the spectral content and interaction with the electron transport.

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A Theoretical Approach for Transient Shock Strengthening in High-energy-density Laser Compression Experiments*

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In high-energy-density shock compression experiments, a desired state of compression can be achieved by passing a shock through a sequence of materials with different acoustic impedances [1,2]. In this study, a theoretical approach for transiently strengthening such shocks is examined. A method based on characteristic analysis semi-analytically solves the problem of a shock passing from one material to another through a region of non-uniform density. By appropriately designing this region, a greater shock strength can be achieved in the second material for a finite duration than in the absence of this region. The method is applied to the design of shock-compression experiments exploring the behavior of planetary mixtures at the conditions thought to exist within the interiors of Jovian planets like Uranus and Neptune [3]. These studies utilize an anvil platform like the diamond anvil cell [4]. With an anvil-based platform, an experimental target is isentropically compressed using the vice-like anvil. A shock wave is then generated via laser-plasma interactions in an ablated material which subsequently passes through the anvil and into the pre-compressed target. It is found that the shock wave passing into the experimental target can be strengthened by bridging the density jump between the anvil material and the target with intermediate density steps. This strengthening is shown in Figure 1 (between solid lines) and is maximized when the density of the intermediate step is equal to the geometric mean of the densities of the anvil and the experimental target (dashed line). Furthermore, it is demonstrated that an exponential density profile between the two materials yields the most effective shock strengthening. The potential shock strengthening is calculated for a wide range of density ratios and incident shock Mach numbers, and the limiting behavior of the strengthening is examined.

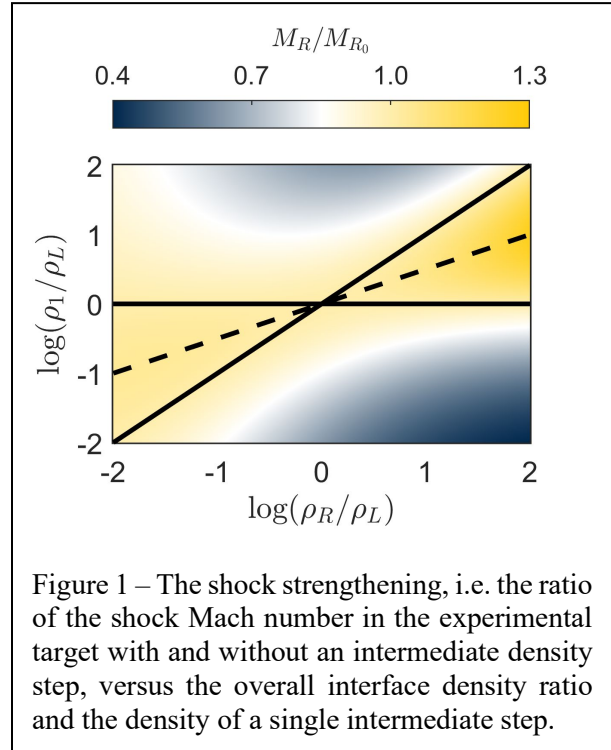


Figure 1 – The shock strengthening, i.e. the ratio of the shock Mach number in the experimental target with and without an intermediate density step, versus the overall interface density ratio and the density of a single intermediate step.

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Abstracts
Poster Session II

Exploration of Parameters for a Future Radiative Shock/Shear Experiment*

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The Shock/Shear experimental platform was created to study turbulence in the High-Energy-Density (HED) regime [1]. The design allows two counter propagating shock waves to cross at the center of an aluminum tracer strip. By isolating shear induced mixing caused by shock waves, the platform helps highlight and study turbulent effects. This study aims to extend the Shock/Shear platform to the radiative regime in order to increase understanding of how radiation affects turbulence. This research will use the Eulerian radiation-hydrodynamics code (CRASH) developed at the University of Michigan which includes block adaptive mesh refinement, multigroup diffusive radiation transport, and electron heat conduction. Characterization of this experiment under different computational parameters such as ablator thickness, foam density, and laser drive energy will increase understanding of the environment necessary to produce a radiative shock, and thus aid the design and development of a radiative Shock/Shear experiment at the National Ignition Facility.

* This work is funded by the U.S. Department of Energy NNSA Center of Excellence under cooperative agreement number DE-NA0003869.

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Exact Theory for Pulsed Laser Induced Photoemission from Biased Surface*

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Photoelectron emission from nanostructures triggered by ultrafast laser fields enables the spatiotemporal control of electron motion in femtosecond and nanometer scales. It is important to ultrafast electron microscopy, free-electron lasers and novel nano-vacuum devices [1-3]. For ultrashort pulsed laser induced photoemission, numerical simulations are typically implemented to study the emission property. Simplified Fowler-Nordheim based models are widely used to calculate the photoemission rate, but it works only in the strong optical field regime. To clearly reveal the underlying physics in different emission regimes, a general theory under ultrashort pulsed condition is highly desirable.

Here, we construct an exact analytical theory for the photoelectron emission from a dc biased surface illuminated by few-cycle laser pulses, by solving the time-dependent Schrödinger equation [4, 5]. The single formulation is valid from photon-driven electron emission in low intensity optical fields to field-driven emission in high intensity optical fields. Our calculations exhibit the coherent interaction of neighboring laser pulses on the photoelectron emission (Fig. 1) and recover the experimentally measured carrier-envelope-phase sensitivity [6] accompanied by a π phase shift in the optical-field regime (Fig. 2). We also find adding a large dc field to the photoemitter is able to greatly enhance the photoemission current and shorten the electron emission pulse.

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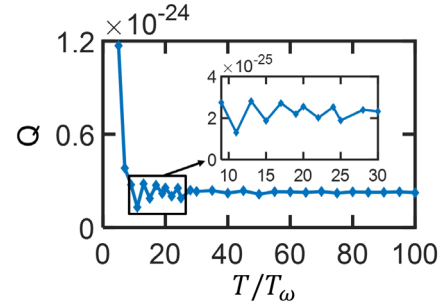


Figure 1 – Total emission charge density Q per pulse due to a laser pulse train, as a function of the ratio of time separation T between adjacent laser pulses over the laser period T_ω . Here, T_ω is fixed as 2.67 fs. The oscillatory behavior of Q (enlarged in the inset) is due to the coherent interaction between neighboring pulses.

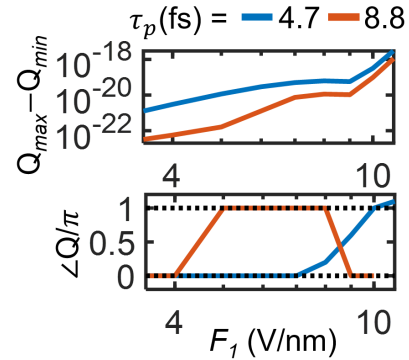


Figure 2 – (a) Magnitude of carrier-envelope phase (CEP) modulation on the total emission charge $Q_{\max} - Q_{\min}$ as a function of laser field F_1 for different pulse duration τ_p ; (b) Phase of CEP modulation on the photoemission charge $\angle Q$ as a function of F_1 for different τ_p .

Computational Investigation of Impulse-Fluence Scaling in X-ray Illuminated Materials on the National Ignition Facility*

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A number of systems in high-energy-density physics involve conversion of x-rays into material impulse through absorption processes. In such systems, x-rays of a given energy are deposited within the material up to a depth dictated by the material's opacity. This energy deposition causes an increase in pressure, driving the heated surface layer to blow off and sending a compressive wave into the bulk of the material.

The material impulse generated by x-ray energy deposition scales with the overall fluence of the incident x-rays. This scaling is sensitive to the x-ray source spectra and opacity. Modeling the relationship between impulse and x-ray source is challenging; analytical models tend to be overly simplistic, entirely ignoring the sensitivity of this relationship to spectral detail.

For a high-fidelity treatment of this problem requires numerical simulation, we utilize the codes Mercury and Ares to simulate x-ray deposition and the resulting impulse generation, respectively. We validate our numerical method and the constitutive models used therein with data obtained from experiments on the National Ignition Facility. We employ this method to quantify the sensitivity of impulse to the source spectrum and the dependence of impulse-fluence scaling on this sensitivity.

* This work was conducted during a 2020 HEDP Summer Student Internship at Lawrence Livermore National Laboratory.

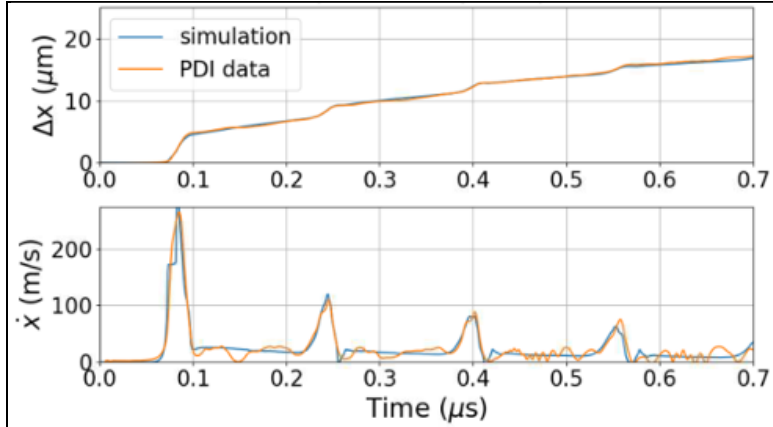


Figure 1 - Simulated tracer particle trajectories vs. PDI data from experiments with Ti-6Al-4V exposed to a Xenon source

Design of a Three-phase Rotating Magnetic Field Power Processing Unit for Inductive Plasmoid Propulsion*

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This work encompasses the design of a three-phase rotating magnetic field power processing unit (RMF PPU) and corresponding switched variable resonant capacitor banks (SVRCs) which drive the antenna currents during the operation of an RMF Thruster. RMF thrusters use an azimuthally rotating magnetic field to generate currents in the propellant plasma and produce thrust via a Lorentz force interaction between the plasma slug and a steady axial bias field. The majority of previous works on RMF propulsion have all employed antenna arrangements consisting of two Helmholtz pairs that form a two-phase RMF. However, the advantage of a three-phase RMF system is to negate the detrimental effects of spatial harmonics in the rotating field [1].

The proposed PPU configuration is a series-loaded resonant sine inverter, which generates kiloampere level currents while only exposing the driving switches to several hundred volts. The primary circuit schematic consists of three half-bridge IGBT units fed

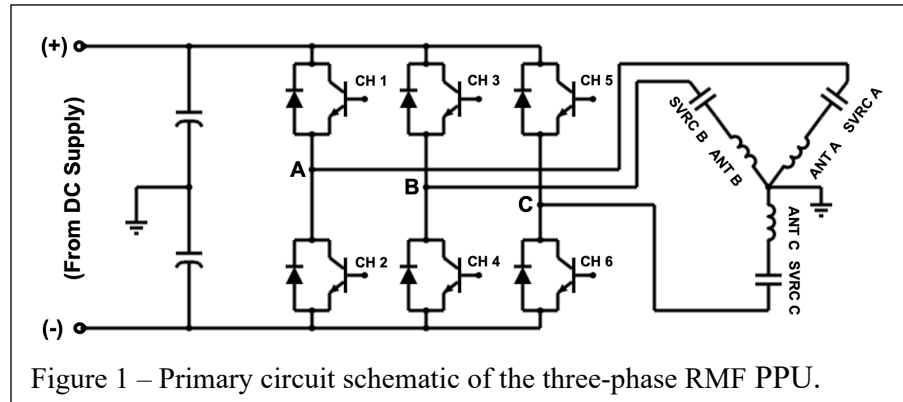


Figure 1 – Primary circuit schematic of the three-phase RMF PPU.

by a backing DC capacitor bank and three SVRCs connected in series to the RMF antennae. The resonant capacitor banks are varied to form an LC oscillator at the desired RMF frequency, which then resonates with the voltage square wave from each half-bridge unit. The SVRCs are designed to accommodate rapid changes of RMF frequency for future optimization studies, and they achieve coarse frequency adjustment in a package smaller than conventional vacuum variable capacitors by using high performance relays to switch in and out multiple parallel capacitor stages.

The expected performance of the three-phase RMF system is peak power of 16 kW per phase at a duty cycle of 10%, a frequency range of 0-300 kHz, and peak antenna currents of 4 kA. The RMF system presented in this work represents the second iteration of an RMF PPU, and the new configuration will allow for longer pulse times, higher RMF frequencies, and lower voltage exposure to the switching circuitry. Presently, the three-phase RMF PPU is under construction, and the switched variable resonant capacitor banks are in the engineering design phase, with initial performance testing taking place in early 2021.

* Work supported by NASA Technology Graduate Research Opportunity 80NSSC20K1168.

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Experimental Confirmation of Transport Model for Solvated Electrons in a Plasma Electrochemical System*

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In this work, the transport of the plasma injected solvated electron is studied using total internal reflection absorption spectroscopy (TIRAS). We previously measured the absorption spectrum for plasma injected electrons at the plasma-liquid interface, which aligns with results produced using nanosecond pulse radiolysis. A theoretical model is used to predict the reaction-diffusive penetration of these electrons, and recent work predicted a $1/3^{1/3}$ exponential scaling of TIRAS intensity with the plasma current density. In this work we perform TIRAS measurements while controlling plasma current density, with the objective of confirming this predicted $1/3^{1/3}$ scaling. By doing so, we find that at higher current densities a scaling of approximately $1/3$ power is observed. However, the scaling is linear at lower concentrations, which we show is due to the transient response of the experiment operating in a modulated mode. Having been demonstrated, this scaling law can predict approximate limits of penetration and interfacial concentration for solvated electrons and hydroxyl radicals, allowing for the enhanced tailoring of a variety of plasma-liquid systems to their applications.

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FARRSIGHT: A Forward Adaptively Refined and Regularized Semi-Lagrangian Integral Green's Function Hierarchical Tree-code Accelerated Method for the Vlasov-Poisson System*

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We present a new forward semi-Lagrangian particle method for the Vlasov-Poisson (VP) system. There is a substantial body of literature devoted to numerical methods for the VP system. Recent methods for solving the VP system include deformable particles [1] and high-order, adaptive [2], and/or discontinuous-Galerkin Eulerian methods [3,4]. In contrast to these, we do not use any operator splitting and obtain the electric field by summing regularized pairwise particle interactions using a hierarchical treecode. We use remeshing and adaptive mesh refinement to maintain an efficient representation of phase space.

The remeshing scheme uses a recursive tree search and biquadratic interpolation, providing for efficiency and good convergence with refinement in mesh size.

Computational cost with the treecode scales as $O(N \log N)$ in N points rather than the prohibitive N^2 of direct summation of pairwise interactions. Our code is further accelerated by running on a GPU. We use the GPU-accelerated treecode BaryTree [5].

We benchmark our method on several standard test cases in the literature: weak Landau damping, strong Landau damping, and a strong two-stream instability. We also study a mismatched beam problem as studied in [1], and find that the AMR allows us to concentrate resolution of the nonlinear beam problem to where the beam is located as it rotates and spirals out into a tenuous halo.

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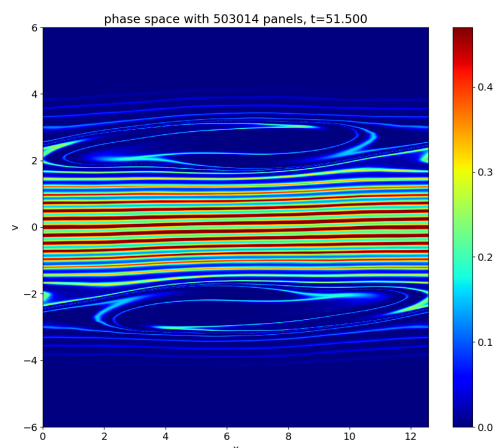


Figure 1 – Image of a strong Landau damping simulation,

$f(x, v, 0) = \frac{1}{\sqrt{2\pi}v_{th}} \exp\left(-\frac{v^2}{2v_{th}^2}\right) \left(1 + 0.5 \cos\left(\frac{x}{2}\right)\right)$. This uses two levels of adaptive refinement, from height 8 to height 10, or a mesh of between 513^2 and 2049^2 points. We see the ability of the AMR scheme to capture the filamentary structures arising in the distribution, and the details of the trapping occurring in the phase space vortex at about velocity 2.5.

High Energy, Relativistic Intensity Laser Channeling and Direct Laser Acceleration of Electrons from an Underdense Plasma*

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Direct Laser Acceleration (DLA) of electrons by a relativistically intense laser pulse is a dynamic and complex process. We perform experiments using the OMEGA EP laser and 2D particle-in-cell simulations to study the acceleration of electron beams from underdense plasma using high-energy, picosecond-duration laser pulses. Gas-jet targets were used to control and change the target density and the focusing conditions are altered by apodizing the beam near-field from having a square profile to a round profile. Proton radiography observes the evolution of the electromagnetic fields within the channel formed and magnetic spectrometers measure the electron spectra. 2-D Particle-in-cell simulations investigate how the plasma density and laser parameters, like energy and focusing conditions, affect the interaction and DLA mechanism to help optimize the experiment configuration.

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Modeling Sheath Dynamics around Water Droplets in Low Temperature Plasmas*

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Low temperature, atmospheric pressure plasmas and their interactions with liquids are important in many applications, including plasma medicine and water treatment. These applications rely on chemically reactive species transporting to the liquid to chemically activate the liquid. Chemical activation is limited by transport since the reactive species must first be produced in the plasma, transport to the surface of the liquid, and diffuse into the bulk liquid. A high surface to volume ratio of the liquid enables rapid activation, as well as a short distance between the location where the reactive species are produced and the liquid. The interface between the plasma and liquid is very complex, due to short-lived species interactions, evaporation of the liquid, charging of the liquid, and sheath dynamics.

The dynamics of the sheath around a water droplet with a high surface to volume ratio immersed in a helium plasma are investigated using the 2D modeling platform *nonPDPSIM*. The helium plasma is formed in a radio frequency (RF) glow discharge at atmospheric pressure, based on the reactor used in Oinuma et al. [1] The RF sinusoidal voltage is assumed to oscillate at 10 MHz. To investigate the dynamics of the sheath, the water droplet is modeled as a dielectric droplet with a relative permittivity of 80, and the liquid phase chemistry is not tracked.

The sheath is shown to oscillate asymmetrically throughout the RF cycle. A snapshot of the electron density at 75 ns from the start of the 40th RF cycle is shown in Fig. 1. Other important properties like polarization, electric field, and electron temperature show oscillations throughout the RF cycle. Changing the RF voltage amplitude, conductivity, and diameter of the droplet show differences in the sheath surrounding the droplet.

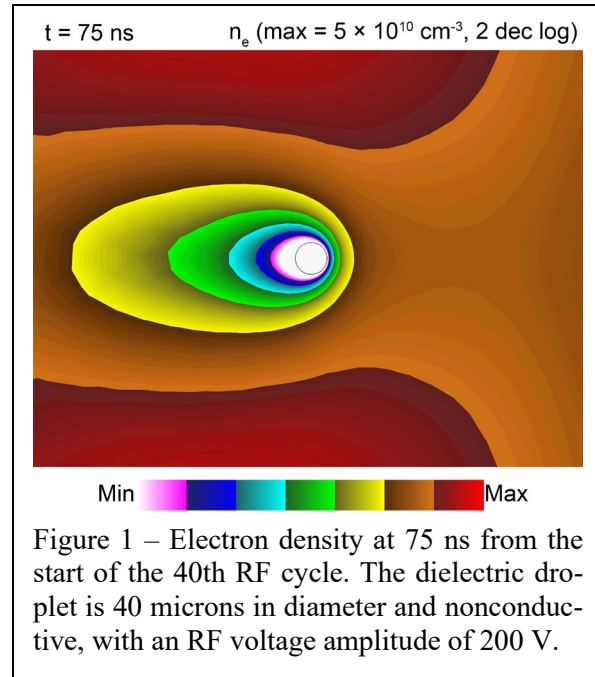


Figure 1 – Electron density at 75 ns from the start of the 40th RF cycle. The dielectric droplet is 40 microns in diameter and nonconductive, with an RF voltage amplitude of 200 V.

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Multi-Fidelity Machine Learning for Extending the Range of High-Fidelity Molecular Dynamics Data*

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Macroscopic models of non-ideal plasmas rely on closure information in the form of equations of state and transport coefficients. Unfortunately, our highest-fidelity models (e.g. Kohn-Sham molecular dynamics) remain very expensive to compute, especially at elevated temperatures where transport is most important. Lower fidelity models such as pair-potential molecular dynamics and analytic theories are orders of magnitude faster but lack the accuracy of the high-fidelity models.

By using machine learning tools, we combine data at the various levels of fidelity to make high-fidelity predictions where it is impossible for the high-fidelity codes to operate. Here, we examine both multi-fidelity Gaussian process regression (MF-GPR) to predict transport coefficients (i.e., diffusion and viscosity) at moderate and high temperatures using calculations done at low temperature with Kohn-Sham molecular dynamics. We find excellent predictions, as measured through a cross validation procedure. Moreover, MF-GPR adds additional value in that it "suggests" the most important new high-fidelity calculations by reporting confidence intervals throughout the extent of the prediction.

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Optimization of a Low Power ECR Thruster Using Two-Frequency Heating*

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Magnetic nozzle thrusters offer many ideal attributes for low-power in-space propulsion. The technology operates by heating a plasma using radiofrequency or microwave power and accelerating this plasma through an expanding magnetic field. This architecture avoids many of the limitations inherent to more mature thruster technologies such as Hall effect and gridded ion thrusters. For instance, it does not require plasma contacting electrodes, can operate using only a single power supply, and enables the use of reactive propellants. However, for over a decade, laboratory experiments using this technology revealed poor thrust efficiencies ($\sim 1\%$) at low input powers (< 100 W), largely negating many of its potential advantages [1].

This trend was recently reversed in experiments using Electron Cyclotron Resonance (ECR) as the heating source for magnetic nozzle thrusters. These thrusters have demonstrated efficiencies above 10% with specific impulses over 1000 seconds while operating at 30 watts, almost an order of magnitude greater than previous studies using helicon or ICP plasmas [2]. While these results show that magnetic nozzle thrusters can be competitive with established propulsion technologies, much work is left to further improve efficiency.

Here, we present the initial results of an optimization experiment aiming to improve performance by adding a second input frequency to the ECR heating. This two-frequency heating is commonly used in ECR ion sources but has not yet been implemented in thrusters [3]. Our experiment uses a set input power and flow rate and divides the power evenly between the two frequencies. Each input frequency can be adjusted from 800-2500 MHz. We use a thrust stand to directly measure the output thrust and efficiency.

By introducing a second frequency, we have formed a two-variable global optimization problem with parameters f_1 and f_2 , which makes testing each possible point prohibitively time consuming. We therefore use a surrogate-based global optimization algorithm to choose new test points based on previous outputs from the thrust stand.

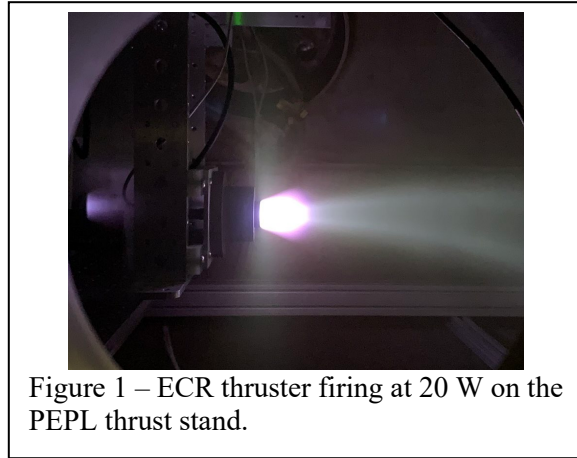


Figure 1 – ECR thruster firing at 20 W on the PEPL thrust stand.

* This work was supported by NASA Space Technology Research Fellowship grant 80NSSC17K0157.

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Phase-Contrast Imaging of Hydrodynamic Shocks in Water with a Betatron X-ray Source*

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Laser wakefield accelerators (LWFA) are a promising alternative for generating bright radiation sources at a fraction of the size and cost of conventional synchrotron-like facilities. The X-ray bursts emitted from a LWFA have sub-micron size, femto-second duration and low beam divergence, thus making them suitable for imaging small-scale dynamic phenomena. In this work we will image the evolution of hydrodynamic shock waves produced by the interaction of a long laser pulse with a stream of water. By taking advantage of the unique properties of plasma-based accelerators, the X-ray pulses will capture the full dynamic evolution of the propagating shock. We have made preliminary measurements and simulations of electron beam and X-ray characteristics, are developing a continuous carbon-free (water) target, and have performed radiograph hydrodynamic simulations of the laser-target interaction using CRASH software.

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Production of Synthetic Phase Contrast Images for Comparison with CRASH Radiograph Output*

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We plan to use the BELLA Hundred TW Thompson laser at the Lawrence Berkeley National Laboratory to perform experiments evaluating shock wave propagation in high-energy-density (HED) plasma research. The laser produces betatron oscillations of a laser-wakefield accelerated electron beam to act as an X-ray source for the experiments. The University of Michigan's Center for Radiative Shock Hydrodynamics (CRASH) software is used to simulate shock propagation through a 120-micron-radius water target at the point of impact of the 1-2 J laser pulse. The output from these CRASH simulations is incorporated into an algorithm developed for Phase Contrast Imaging to obtain synthetic images of the shock front at a distance of 490 cm. These images may be compared to the synthetic radiographs of similar phenomena produced by CRASH in earlier experiments in order to capture finer details of the dynamic evolution of shock waves propagating in HED plasma environments.

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Using Reduced Order Modeling to Understand the Physics of Injection in Laser Wakefield Acceleration*

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Laser Wakefield Acceleration (LWFA) is a process by which plasmas are excited by a laser leading to the acceleration of electrons. The process is highly nonlinear, leading to difficulties in developing an accurate theoretical model for a priori prediction. Recent experiments at the Rutherford Appleton Laboratory's (RAL) Central Laser Facility (CLF) in the United Kingdom using the 20 TW, 5Hz repetition rate Astra-Gemini laser has produced new results in LWFA research, that can allow unprecedented exploration of the parameter-space of laser and target conditions. Experimental measurements can inform scaling laws for the creation of more robust prediction and control models. With the new data constraining previous scaling laws, models can be extended into new ranges. These data allow the construction of reduced order models that can make predictions without the need for full scale simulation.

* Work supported by the National Science Foundation

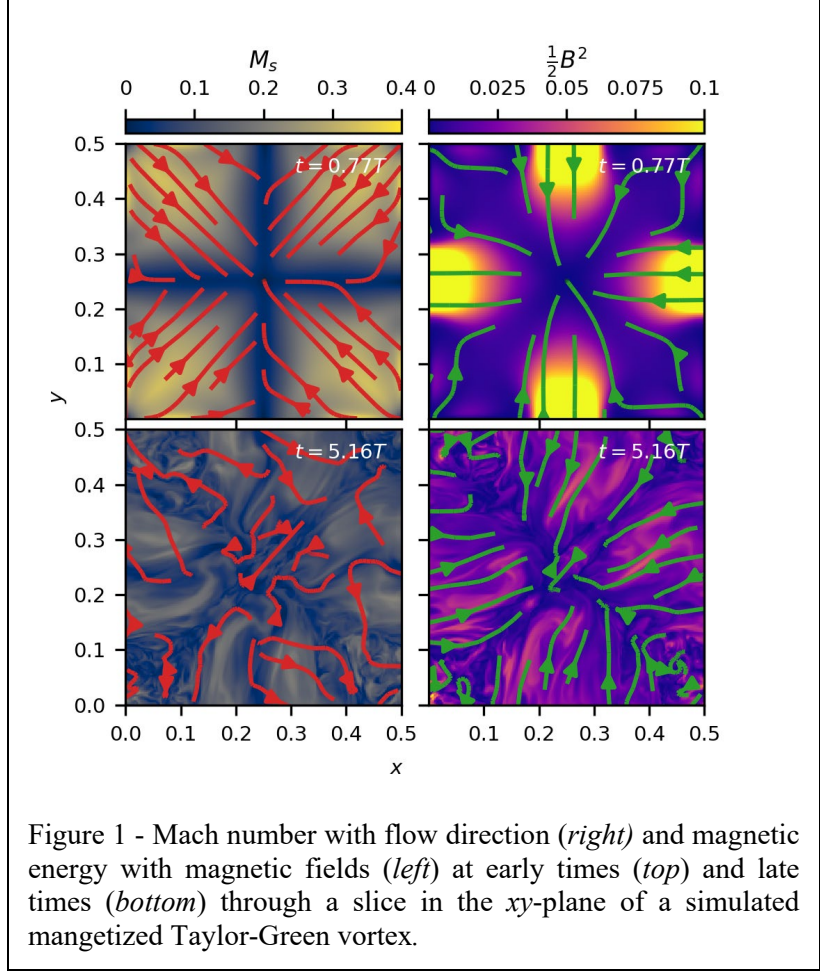
Abstracts
Poster Session III

Decaying Magnetized Turbulence in the Taylor-Green Vortex*

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Magnetized turbulence in terrestrial and astrophysical plasmas mediates an exchange of magnetic, kinetic, and thermal energies between different length scales. Capturing these energy exchanges is essential for high fidelity numerical plasma simulations. Accurately modeling magnetic turbulence in simulations requires high temporal and spatial resolutions even in idealized systems. For the purpose of studying the formation of magnetized turbulence, we ran high resolution simulations of the magnetized Taylor-Green vortex: a system where magnetized turbulence develops from a decaying flow without an external driving force [1]. We found that regardless of initial field strength, magnetic energy came to dominate over kinetic energy in all cases. Magnetic fields also played a vital role in facilitating energy exchange from large scale kinetic energy to magnetic energy on much smaller scales, which has not been apparent in previous studies on driven magnetized turbulence. This contributed to a flatter magnetic and kinetic energy spectra after evolving for several dynamical times with more energy at smaller length scales. In general, we found magnetic fields to be essential to the behavior of the turbulence.



* Work supported by Blue Waters at the National Center for Scientific Computing and the Michigan Institute for Plasma Science and Engineering.

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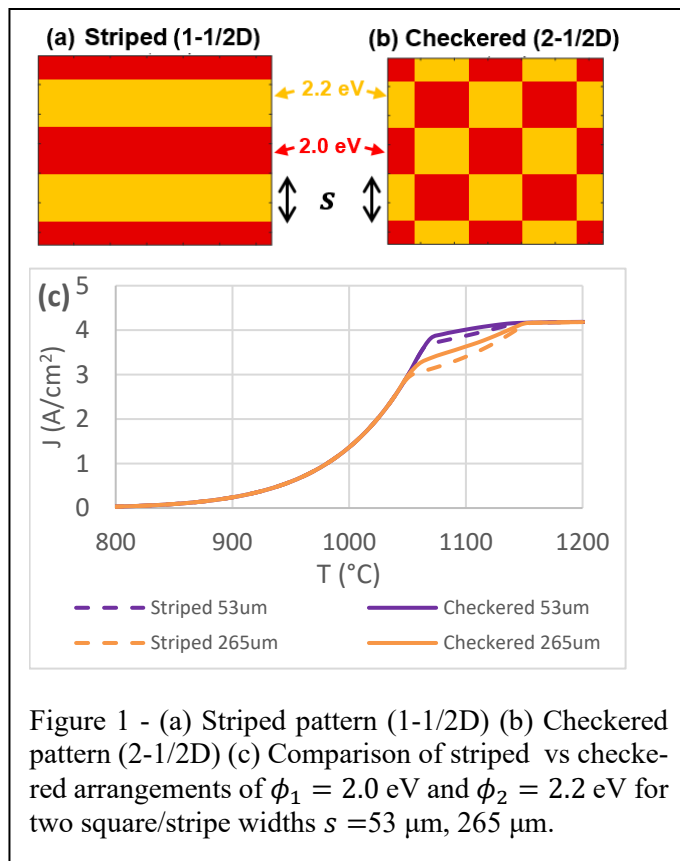
Analysis of Miram Curves with Two-Dimensional Work Function Distributions*

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The performance of thermionic cathodes is commonly characterized by its Miram curve, a plot of anode current vs cathode temperature that shows the transition from temperature limited electron emission to a space charge limited regime. This transition is known as the knee in the curve, and the physical reasons for its shape have not been definitively identified. An ideal 1D cathode has a Miram curve with a highly sharp knee, while experimental curves exhibit a much smoother and more rounded knee. This matter is important, since thermionic cathodes are almost always operated in the vicinity in the knee for considerations of thermal stability and cathode life.

We extend a model [1] of a 1D planar diode with a thermionic cathode in which the Poisson and Vlasov equations are solved in 3D assuming an infinite magnetic field. Our approach allows us to study how various 2-dimensional cathode work function distributions, both realistic and idealized, can impact the shape of the Miram curve. For example, Fig. 1c shows a comparison of a striped (Fig 1a) and a checkered (Fig. 1b) pattern of two work functions (2.0 & 2.2 eV) where the stripe width s has been set to either 53 or 265 μm and demonstrates how emission in the knee region is modified through the action of 2D space charge forces. In this work, we show (i) that discrete work function distributions may lead to smooth Miram curves, (ii) that even with a large fraction of the cathode being non-emitting, the anode current is still governed by the 1D Child-Langmuir Law as if the entire cathode were emitting, and (iii) that decreasing the length scale of work function variations leads to a sharper Miram knee.



* This work was supported by the Defense Advanced Research Projects Agency (DARPA) under Contract HR0011-16-C-0080.

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Contact Engineering in 2D-Material-Based Electrical Contacts*

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The engineering of efficient electrical contact to two-dimensional (2D) layered materials is crucial for the development of industrial-grade 2D-material-based electronics and optoelectronics. The undesirably large contact resistance, in particular, is a major obstacle and needs to be minimized.

We develop a new model to quantify electrical contact resistance and current distribution for 2D/2D and 2D/3D metal/semiconductor contact interfaces, based on a self-consistent transmission line model (TLM) [1] coupled with the thermionic charge injection model [2] of 2D materials (Figs. 1a and 1b). Results are validated with existing experimental works. We further model the effect of interfacial roughness at the 2D/3D electrical contact by including a Schottky barrier height (SBH) fluctuation term, i.e. $\Phi_B \rightarrow \Phi_B + \Delta\Phi_B$, where $\Delta\Phi_B$ is calculated by assuming that the SBH fluctuation follows a Gaussian distribution [3].

Figure 1c shows the SBH variation has a dramatic effect on the contact resistance. In general, R_c is reduced significantly in the presence of roughness. Such reduction is particularly effective for MoS₂/Au contact with large SBH (e.g. 0.3 eV).

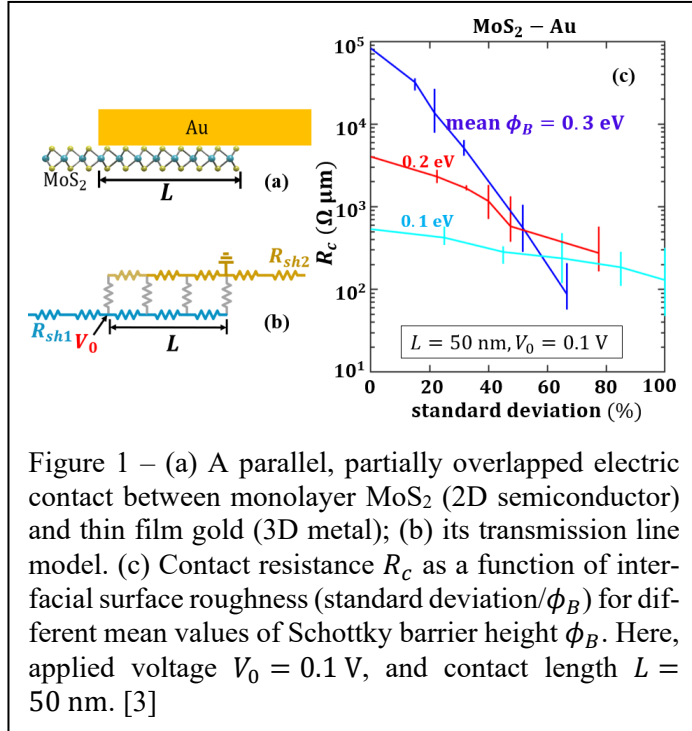


Figure 1 – (a) A parallel, partially overlapped electric contact between monolayer MoS₂ (2D semiconductor) and thin film gold (3D metal); (b) its transmission line model. (c) Contact resistance R_c as a function of interfacial surface roughness (standard deviation/ ϕ_B) for different mean values of Schottky barrier height ϕ_B . Here, applied voltage $V_0 = 0.1$ V, and contact length $L = 50$ nm. [3]

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Development of a Gas-Puff Z-Pinch Experiment for the 1-MA, 100-ns MAIZE Linear Transformer Driver*

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The Z-machine at Sandia National Laboratories is instrumental in plasma physics research across a range of applications. University-scale z-pinch experiments, such as gas-puff z-pinches, can inform the high-value experiments conducted on the Z facility. A gas-puff z-pinch requires gas to be puffed into the anode-cathode gap, which is then pulsed with a high voltage [1]. The gas is ionized, accelerated, and compressed as the current flows across the electrodes, allowing for study of pinch phenomena including fusion reactions [2]. The initial ionization condition of the gas-puff prior to compression is poorly understood. Additionally, how this affects fusion, which is largely the result of micro-pinch instabilities, is also poorly understood. We report on the preliminary results from the newly developed experimental capability on the MAIZE Linear Transformer Driver at the University of Michigan

* Work supported in part by a seed grant from the Michigan Memorial Phoenix Project and the NNSA Stewardship Sciences Academic Programs under DOE Cooperative Agreement DE-NA0003764.

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Gas Plasma Effects on Chemoresistance Ovarian Cells

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Gas plasma has recently become a topical area of research due to widespread applications in medicine. Current promising medical applications are focused on oncotherapy, wound healing and skin diseases, ophthalmology, virus inactivation, biofilms, dentistry, and other diseases. Plasma is a cocktail of chemical and physical factors. Transferring of plasma reactive agents to the targets is the base of plasma treatment. These reactive agents, including electromagnetic radiation, reactive oxygen and nitrogen species, and charged particles. [1]

Herein, we evaluated the efficacy of plasma on ovarian normal and cancer cells. To this end, first, cisplatin-resistance ovarian cancer cells were exposed under plasma. Then, primary GCs cells were exposed under the same condition of plasma therapy. Along with the physical characterization of the plasma jet, MTT, AO/PI, HE, RT-PCR assays have been conducted. Besides, we measured the long-lived reactive oxygen and nitrogen species concentration in the culture mediums.

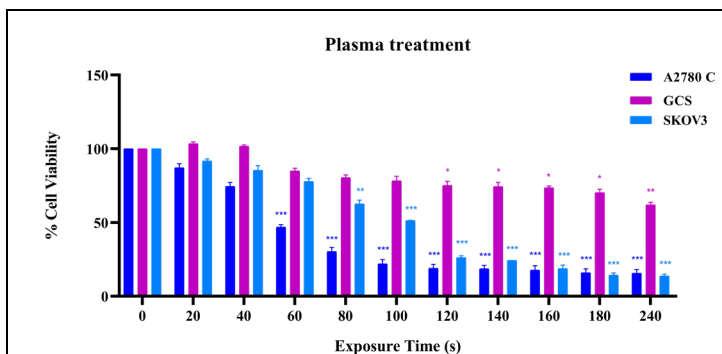


Figure 1 - Viability of GCs, SKOV-3, and A2780 CP cells treated with direct plasma treatment as measured by the cell viability assay. The percentages of surviving cells from each cell were calculated relative to controls. All experiments have replicated a minimum of three times. Data are presented as means $\pm$ S.D. (* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ versus control).

Our results as shown in Figure 1, revealed that the plasma has a highly selective effect of up to 120 seconds so that healthy cells have not been affected by plasma irradiation while the viability of cancer cells was significantly reduced ($P < 0.001$). From 120 seconds to 180 seconds we saw a weak selective effect of plasma. Thus, the survival of cancer cells in comparison to their control groups was significantly reduced ($P < 0.001$) while healthy cells were also affected by plasma irradiation and their survival changed ($P < 0.05$). From 180 to 240 seconds, the survival of healthy cells was significantly reduced than the control group ($P < 0.01$). Also, our data confirm plasma induces apoptosis in cisplatin resistance ovarian cancer through a combination of electric field and long-lived reactive oxygen and nitrogen species such as H_2O_2 , NO_2^- .

Finally, we concluded plasma as an emerging technology creates a very promising plasma-based multimodality treatment for ovarian cancer.

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Interactions of Porous Dielectric Materials with Atmospheric Pressure Plasmas*

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Low temperature plasma (LTP) interactions with complex surfaces is of significant interest for functionalization and sterilization. The behavior of LTPs on planar uniform surfaces has been investigated in detail. However, industrial materials typically have rough and non-uniform surfaces. Understanding the interaction of plasmas with such surfaces is important to many applications including catalysis and biomedical materials processing. One important type of nonplanar morphology is a porous surface. In this work, we discuss results from a computational investigation of atmospheric pressure plasma interactions with porous dielectric surfaces and plasma penetration into pores.

This investigation was performed using the 2-D hybrid plasma model *nonPDPSIM* [1]. The model solves Poisson's equation for the electrical potential together with continuity equations for neutral and charged species. The model solves Boltzman's equation to obtain electron energy distribution functions to provide rate coefficients while also accounting for surface charging and secondary electron emission. In this work, surface ionization waves (SIW) were investigated while propagating on a porous dielectric surface in atmospheric pressure humid air. Key differences between positive and negative polarity plasmas in being able to penetrate into pores were identified. The range of applied voltage magnitude that is able to sustain a SIW and penetrate into pores was identified for different polarities. Plasma penetration into pores was studied for different shapes of pores, different size of opening (including close to the Debye length) and varied distance of the pores from the powered electrode.

* Work was supported by DOE Fusion Energy Sciences (DE-SC0020232) and the National Science Foundation (IIP-1747739, PHY-1902878).

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Magnetic Field Generation at Extreme Laser Intensities*

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Some of the most energetic astrophysical bodies are theorized to have extreme magnetic field strengths defined by a large magnetization parameter $\sigma_{cold} = B^2/\mu_0 n_e m_e c^2$. In the laboratory, the highest energy laser-driven experiment studying magnetic reconnection was able to reach the "semi-relativistic" regime where $\sigma_{cold} \approx 1$ for electrons and $\sigma_{cold} \ll 1$ for ions [1]. This experiment was performed using a laser intensity of $\sim 10^{19}$ W/cm², much less than $>10^{23}$ W/cm² expected to be reached by the next generation of multi-petawatt power laser systems e.g. ELI, ZEUS. At these extreme intensities, quantum electrodynamic (QED) effects such as radiation reaction may become important. Using the QED module in the OSIRIS particle-in-cell code, we perform simulations to study magnetic field generation in this regime to understand how the field strength scales with laser intensity. The implications of this scaling for studying relativistic magnetic reconnection in the laboratory will be discussed.

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New X-Pinch Platform and Diagnostics for the MAIZE Facility

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X-pinchs, formed by driving intense current through the crossing of 2 or more wires, provide an excellent platform for the study of “micro-pinchs” due to their propensity to generate a single micro-pinch at a predetermined location in space (i.e., where the wires cross) [1, 2]. Ideally, micro-pinchs compress to very small radii ($\sim 1\text{ }\mu\text{m}$) leading to pressures on the order of $\sim 1\text{ Gbar}$ for currents on the order of $\sim 0.1\text{ MA}$. However, the fraction of the total current that is driven through the dense micro-pinch plasma at small radii versus that being shunted through the surrounding coronal plasma at larger radii is not well known. To allow for the study of micro-pinchs and their current distribution on the 1-MA MAIZE facility, an imaging Faraday rotation diagnostic, as well as corresponding X-pinch load hardware, are being developed [3]. Presented are preliminary experimental results investigating various X-pinchs on the MAIZE LTD.

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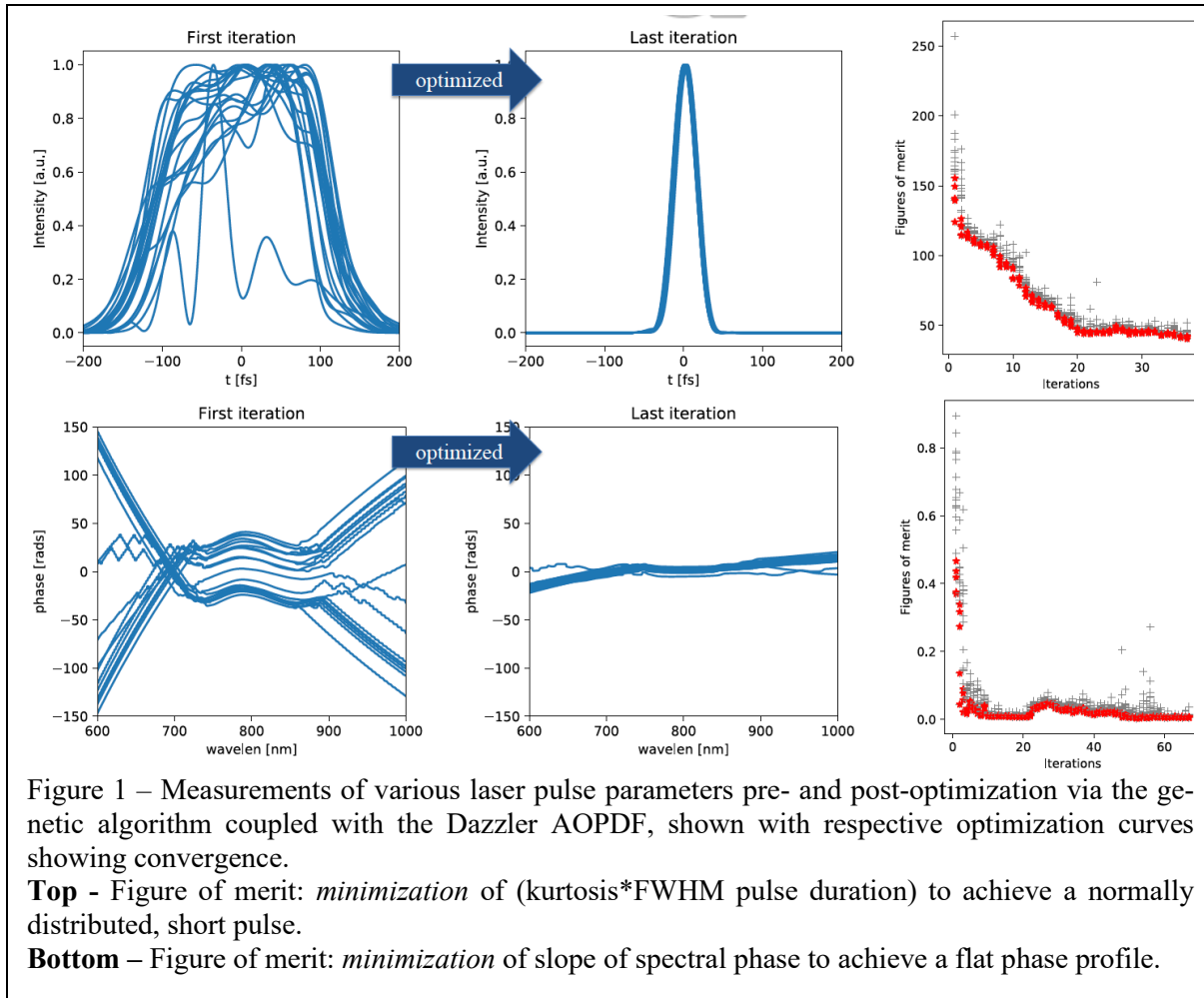
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Optimization of High Repetition-rate Laser-driven Particle and Radiation Sources Using Machine-learning Techniques

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Many applications of laser-driven particle sources benefit from operation at high repetition rate. Here, 20 milliJoule laser pulses are generated at 0.5 kilohertz repetition rate for a number of laser-plasma interaction experiments, including laser wakefield acceleration and $k\alpha$ x-ray generation. A genetic algorithm is implemented in the execution of these experiments using control of adaptive optics and a Dazzler acoustic-optic programmable dispersive filter. Utilizing the genetic algorithm in our laser-plasma interaction experiments allows for a heuristic search of optimal laser pulse parameters or target parameters for each experiment.



Physical Differences Between Xenon and Krypton Operation on a Magnetically-Shielded Hall Thruster*

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Hall thrusters are an electric propulsion device with high thrust density, moderate specific impulse, and relatively long operational lifetimes. This last trait has been enabled by magnetic shielding, a technology that prevents energetic ions from eroding thruster channels. Traditionally, Hall thrusters have operated on xenon, but krypton provides an attractive alternative at its lower cost and higher specific impulse for a given power. However, the use of krypton has been limited by its poor efficiency compared to xenon on both unshielded¹ (US) and magnetically-shielded² (MS) Hall thrusters. This study investigates why this performance gap exists on shielded Hall thrusters and how it compares to unshielded thrusters.

The H9, a 9-kW MS Hall thruster, was operated in the Large Vacuum Test Facility at the University of Michigan at 300 V and 15 A on both xenon and krypton. A probe suite and a thrust stand measured various efficiency contributions towards the anode efficiency and the anode efficiency itself. Results from this study indicated that mass utilization efficiency and current utilization efficiency are the main reasons why the krypton efficiency is lower than that of xenon; both the mass and current utilization efficiencies were lower for krypton than xenon by about 12%.² The gap in mass utilization efficiency is comparable to that on an US thruster, but the gap in current utilization efficiency is about 9% larger.^{1,2}

The similar gaps in mass utilization efficiencies for the US and MS case are surprising considering the differences in magnetic field topology. A comparison of the effect of electron temperature on the ionization rate is made to better understand this phenomenon. A given change in electron temperature leads to a larger change in ionization cross-section for krypton than for xenon.³ Because the profile of electron temperature on a MS thruster is higher along centerline but lower along the walls, the net effect on the krypton efficiency on a US thruster compared to a MS thruster is approximately the same. The results from this study can be used to better optimize future operation of magnetically-shielded Hall thrusters.

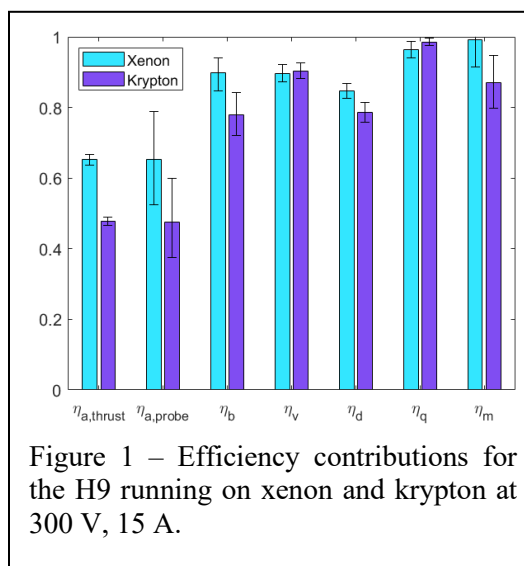


Figure 1 – Efficiency contributions for the H9 running on xenon and krypton at 300 V, 15 A.

* Work supported by the National Science Foundation.

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Towards Predicting Electron Beam Charge upon Phase Control in Laser Wakefield Accelerators Using Supervised Learning Techniques

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High-repetition-rate laser systems have been widely used with evolutionary algorithms to solve optimization problems in the field of relativistic laser-plasma interactions¹. However, evolutionary algorithms usually provide little information other than the optimized result, which can be hard to interpret. Machine learning methods can generate predictive models to reveal more information in the dataset and help understand the physics relations². In this work, we measured the electron beam charge from a laser-wakefield accelerator upon changing the laser wavefront using a deformable mirror. Through model training with weight learning, we predict the electron beam charge given the wavefront using four supervised learning methods: random forest, neural networks, deep joint-informed neural networks³, and Gaussian process. We show that generating higher beam charge favors specific wavefront by ranking the feature importance. We show that machine learning can help understand the measured data quality as well as recognize irreproducible data and outliers. We also include virtual measurement errors in the dataset to exam the model performance. This work demonstrates how machine learning methods can benefit the data analysis and physics interpretation in a nonlinear LPI problem.

* Work supported by AFOSR FA9550-16-1-0121

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Fluid Simulations of Magnetic Nozzle Thruster Including Plasma Source

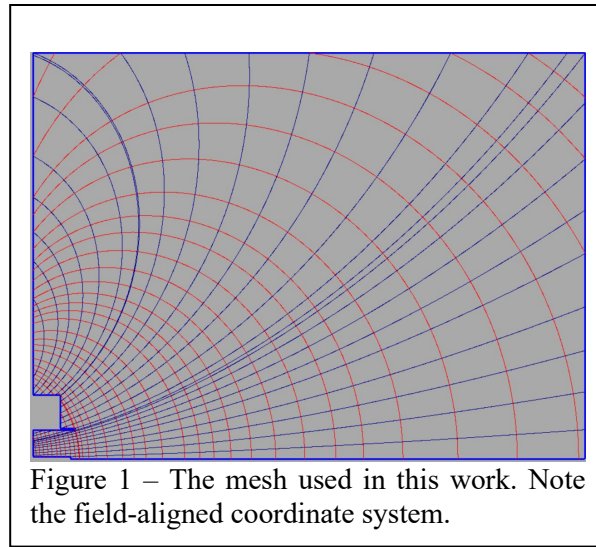
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Magnetic nozzles are plasma acceleration devices in which a plasma expands along a divergent magnetic field, accelerating to produce thrust. Magnetic nozzles offer several potential advantages over traditional electric propulsion devices like Hall thrusters and gridded ion thrusters. They are propellant and plasma source-agnostic, making them an attractive general-purpose plasma acceleration mechanism with possible applicability to in-situ resource utilization. Additionally, as plasma is confined away from the device walls by a strong axial magnetic field, low power (less than 100 W) devices employing magnetic nozzles may suffer from lower plasma wall losses than competing technologies, making them ideal for the emerging smallsat market. However, these possible advantages have not yet materialized, and efficiency remains fairly low. Thus, no magnetic nozzles have yet been flown on orbit.

Recently, rapid design optimization has succeeded in making remarkable efficiency gains in devices employing magnetic nozzles¹, but this has been limited to manually altering device geometry, testing, and repeating. This process is expensive and slow, and would be dramatically improved and sped up if sufficiently predictive fluid models were available. However, gaps in our knowledge of the physics of electron detachment from the guiding field lines and the nature and type of electron cooling in the nozzle plume prevent current fluid models from being predictive enough to be useful in rapid design optimization.

In this work, we present an advanced fluid model of a magnetic nozzle and plasma source using the Hall2De fluid Hall thruster code developed at the Jet Propulsion Laboratory. This model solves the 2D axisymmetric ion and electron fluid equations on a magnetic field-aligned mesh and treats neutrals as ballistic. Most notably, this model solves a full electron fluid energy equation instead of pre-supposing a polytropic equation of state, allowing more nuanced investigation of the mechanism of electron cooling. Comparisons between the present model and experiment show that classical fluid physics alone cannot explain electron cooling in the studied devices and suggest that wave-driven anomalous resistivity may be needed to correctly model plasma expansion in magnetic nozzles. This is in line with recent experimental results suggesting that wave driven collisionality due to the lower hybrid drift instability (LHDI) may dominate classical collisions in magnetic nozzle plumes².



* Work supported by the Air Force Office of Scientific Research

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Abstracts
Poster Session IV

Utilizing a Global Model to Identify Relevant Reactions in Chemically Complicated Plasma Systems*

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Plasma chemistry mechanisms in gaseous breakdown, such as plasma assisted combustion (PAC) systems, involve many species, reactions, and spatially dependent system variables, e.g. species' densities and temperatures, which become prohibitively computationally expensive. Global models can be used to prioritize and thereby reduce the number of reactions and species, where variables of interest show little spatial dependence, and where plasma sheath and surface processes can be either simplified or neglected.

We present a kinetic global model framework (KGMf [1]) that employs spatially-averaged energy and particle balance equations, chemical reactions in bulk plasma, and takes into account time-dependent power absorption via Joule heating, to identify the impact of relevant reactions on temperatures and species' densities. The electron energy distribution function (EEDF) can be either predefined (e.g. Maxwellian) or self-consistently computed with coupled Boltzmann equation solver. The sensitivity analysis is performed to evaluate the uncertainty of simulation results based on uncertainty of input parameters, which can be performed completely with the KGMf. The uncertainty of input parameters is specified in a single input text file and the resulting sensitivities of the variables of interest are saved into HDF5 formatted file for easy retrieval. PumpKin [2] and the KGMf's results, i.e., the stoichiometric matrix and the temporal evolutions of species densities and reaction rates, are used to reduce the reaction set, which can still capture the time evolution of selected system variable (e.g., temperature and density of target species).

The sensitivity analysis and the determination of dominant pathways are performed in 1% H₂ - 0.15% O₂ - Ar mixture at $p = 300$ Torr and gas temperature $T_g = 500$ K, excited by nanosecond pulse plasma with a repetition frequency $\nu = 20$ kHz and coupled discharge energy of 2.6 mJ/pulse [3].

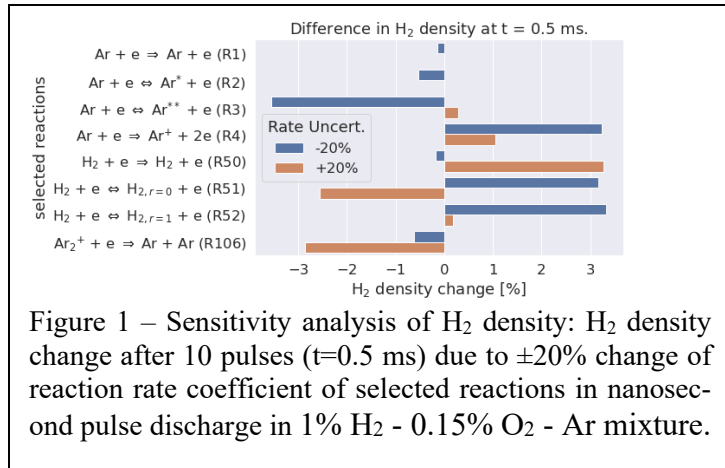


Figure 1 – Sensitivity analysis of H₂ density: H₂ density change after 10 pulses (t=0.5 ms) due to $\pm 20\%$ change of reaction rate coefficient of selected reactions in nanosecond pulse discharge in 1% H₂ - 0.15% O₂ - Ar mixture.

* Work supported by Air Force Office of Scientific Research (AFOSR) Grant No. FA9550-18-1-0062 and U.S. Department of Energy (DoE) Plasma Science Center grant DE-SC0001939.

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Characterization of Pulsed-power Magnetized Jets on MAIZE*

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We present the first results of a laboratory-astrophysics experiment with the goal of characterizing magnetized plasma jets on the Michigan Accelerator for Inductive Z-Pinch Experiments (MAIZE) in the Plasma, Pulsed Power, and Microwave Laboratory at the University of Michigan. We aim to explore the interactions of magnetized plasma flows with external magnetic fields and the behavior of the different plasma flows created by conical wire-arrays (hot coronal plasma and radiatively cooled jets). In these first preliminary results, we focus on the structure and development of shock instabilities.

To generate the magnetized plasma flows, we used MAIZE to ablate 100-micron, aluminum wire arrays with currents in the order of 500 Kilo-Amp with a rise time of 250 ns. We use a conical array to drive an axial plasma jet, while a Helmholtz coil provides a uniform 5-T axial magnetic field. Our first images come from visible self-emission and shadowgraphy (532 nm), captured by a fast-frame camera, showing the structure and evolution of the plasma jet.

* This work is supported by the U.S. Department of Energy's NNSA SSAP under cooperative agreement numbers DE-NA0003869 and DE-NA0003764.

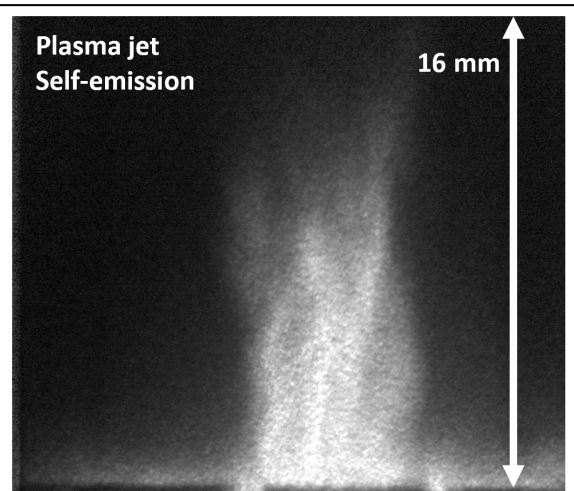


Figure 1 – Self-emission image of the aluminum plasma jet at 216 ns after pulse start. The jet is traveling at around 100 km/s and has an estimated density and temperature of 10^{-4} g/cc and 20 eV respectively.

Controlling Composition of Particles Grown in Dusty Plasmas*

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Nanoparticles (NPs) are very fine, nanometer sized clusters of atoms that are important in many fields. They can have unique chemical and optical properties which depend on the composition of the nanoparticles. Low temperature plasmas have been known to produce particles or “dust” and decreasing their impact has been an active area of research for semiconductor processing for years. More recently, low temperature plasmas have been used to purposely create NPs. The highly non-equilibrium and dynamic environments of plasmas can be used to produce particles with specific compositions that may otherwise be difficult through traditional methods. Particles that are made of distinct layers, “core-shell” NPs, have been made experimentally using plasmas, but the specific mechanism for particle formation and growth is still speculative [1].

In this work, results of a computational study of the formation of “core-shell” nanoparticles in low temperature plasmas will be discussed. Specifically, particles with a Ge “core” surrounded by a Si “shell” were modeled growing in laboratory scale tube reactors from Ar/SiH₄/GeH₄ gas at a few Torr. A 3D kinetic model for dust particle dynamics and growth, the Dust Transport Simulator (DTS), coupled with a multi-fluid plasma simulator, the Hybrid Plasma Equipment Model (HPEM), was used in this investigation. Results showing particle growth rates and composition as functions of inlet composition and power will be discussed.

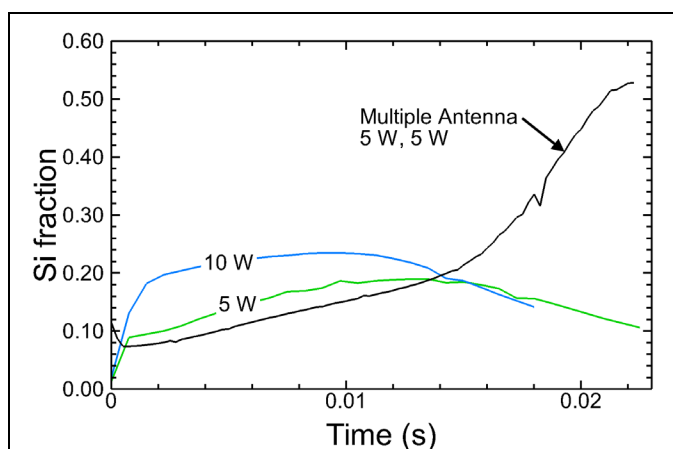


Figure 1 – Si fraction of nanoparticles while grown in the plasma over time for different power: single antenna at 5 W (green) and 10 W (blue), and using multiple antenna placed strategically with 10 W total. This shows that the plasma can be manipulated to form nanoparticles with controllable compositions.

* Work supported by Army Research Office MURI Grant W911NF-18-1-0240 and Department of Energy Office of Fusion Energy Science.

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Effect of Flux Conservers on Inductive Pulsed Plasmoid Thrusters *

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Inductively driven pulsed plasmoid thrusters are propulsion devices which function by inducing strong currents in plasmas using electromagnetic fields to form plasmoids, coherent plasma structures which can then be ejected at high speed to produce thrust. These devices have several potential advantages over state-of-the-art steady-state propulsion schemes [1]. Recently, both the Department of Defense and NASA have expressed interest in the Field-Reversed Configuration thruster, a design which borrows heritage from the fusion community [2].

A common feature of the FRC confinement device used in fusion research is the inclusion of flux-conserving rings. These are conductive metal bands surrounding the plasma which serve to increase the magnetic pressure outside the plasmoid separatrix [3]. Flux-conserving rings, or flux conservers, are often included in FRC thrusters as well, with the argument the increased magnetic pressure will help to accelerate the plasmoid [4]. However, quantitative evidence of the benefits of flux conservers is lacking.

To analyze the effect of these flux conservers, we present a circuit analysis of the FRC thruster. The device is abstracted into several current loops which couple to each other inductively. After establishing this model, two primary assumptions are made: elimination of loss terms and the limiting case of instant current spin-up, in which the driver coil couples all its energy into the plasma instantaneously. By making these assumptions we arrive at a closed form expression for thruster efficiency as a function of initial conditions.

It is found that in the limit of instant current spin-up, in which the driver coil couples all its energy into the plasma instantaneously, flux conservers represent an efficiency loss to the thruster. This result suggests that conductive structure elements should be minimized in the designs of future thrusters to reduce losses unless confinement is an important goal.

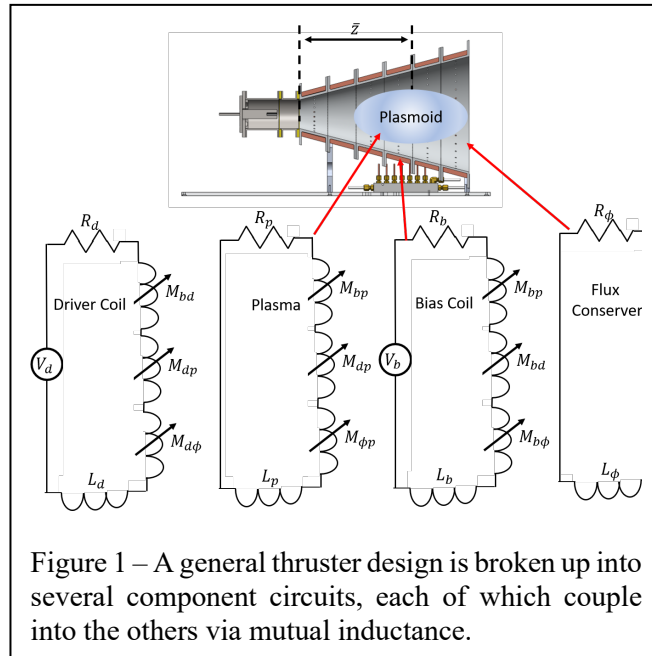


Figure 1 – A general thruster design is broken up into several component circuits, each of which couple into the others via mutual inductance.

*Work supported by NASA Space Technology Research Fellowship 80NSSC18K1190.

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Experiments Relevant to the Interaction of Stellar Radiation with Nearby Gas Clouds*

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Hot, massive stars emit an abundance of photons with energies that ionize the surrounding interstellar medium. Gas clouds near the star respond to the irradiation in a variety of ways. If the cloud is optically thick to incident photons, then the photons will deposit at the cloud edge and drive a shock into the cloud. Further star formation may result. If the cloud is optically thin, then the photons deposit throughout the cloud, causing cloud heating, expansion and dissipation. Lengthy timescales of evolution make single cloud observations impractical. Simulations and laboratory astrophysics experiments are needed to fully understand these interactions.

We replicate these phenomena using optical depth-scaled laboratory astrophysics experiments. A laser-irradiated, thin-gold foil represents the star. A primarily carbon foam sphere represents the cloud. Cloud responses - hydrodynamic limits - are chosen by careful selection of sphere parameters, such as composition, density and diameter. A preliminary comparison between optically thick experimental data and a simple analytic model is presented.

* This work is funded by the U.S. DOE NNSA Center of Excellence under Cooperative Agreement number DE-NA0003869, and the NLUF Program, grant number DE-NA0002719, and through the LLE, University of Rochester by the NNSA/OIFC under Cooperative Agreement No. DE-NA0003856. This work is funded by the LLNL under subcontract B614207.

Investigation of Techniques to Mitigate the Erosion of a Mesh Reflector Exposed to a Hall Thruster Plume

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Hall effect thrusters (HETs) have many advantages over traditional chemical systems. Due to their high specific impulse HETs have much higher propellant efficiencies. Thus, they can support a wider range of missions ranging from LEO to deep space. It is no surprise then that they have become one of the most popular choices for many new and upcoming missions. While EP devices can offer a higher propellant fraction, they also present a unique problem for spacecraft integration: the higher exhaust velocities—typically in the 10's of km/s—produced by EP devices can bombard spacecraft surfaces and cause erosion [1]. This is especially problematic for deployable structures, like communication dishes, which can extend into denser plume regions. Previously, we developed a model to predict the erosion of the meshed reflector surface used in these dishes [2]. The predictions of this model were experimentally verified [3]. We found that material sustained significant damage to the material in a short period of time when exposed to the plume of a hall thruster, in accordance with our predictions.

When we then use the calibrated model to predict the erosion of a dish in a typical orbital configuration we find that although there is not significant damage initially, over the long operational lifetime of an EP missions even the relatively low ion flux at the reflector location can become a issue. Given that this erosion is unavoidable, there is an apparent need to develop methods to mitigate this erosion. To this end, we devised an experiment to examine systematically two different mitigation strategies. The first was an active method, reverse biasing. By raising the electrical potential of the reflector array it may be possible to repel and reduce the energy of incoming ions, thereby reducing erosion. The second is a passive method, shadow shielding. A small obstruction is placed upstream, near the thruster, in order to shadow a large downstream area from plume ions. The effect of this obstruction (carbon shield) is shown in Fig. 1. We found that both mitigation strategies were successful in either reducing, or completely eliminating the erosion of the reflector material.

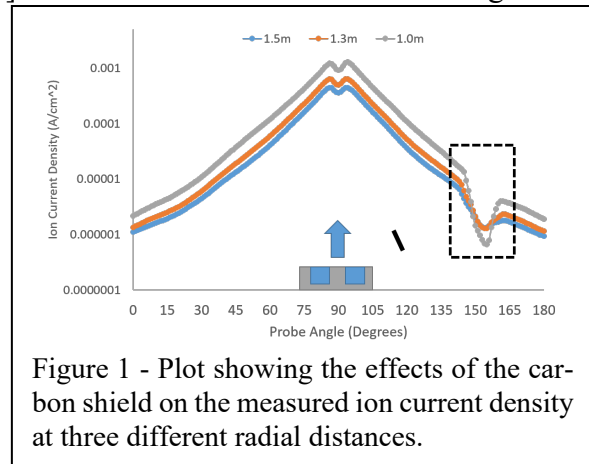


Figure 1 - Plot showing the effects of the carbon shield on the measured ion current density at three different radial distances.

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Low Frequency Instabilities in a Magnetic Nozzle*

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Magnetic nozzles are a type of electric rocket consisting of a diverging magnetic field through which a plasma is ejected. As a radial pressure gradient forms, an electron diamagnetic drift induces a magnetic field that opposes the applied field, which in turn accelerates the electrons outwards. The electrons thus generate an ambipolar electric field that accelerates the ions, generating thrust. Given that the magnetic field is primarily parallel to the thruster body, erosion is mitigated, allowing the potential for long duration missions. Furthermore, as most plasma generation mechanisms involved in magnetic nozzles rely on electron heating, they can operate on a wide array of propellants, enabling mid-mission refueling.

Despite their prolific advantages, magnetic nozzles have not yet operated in space. The main reason behind this fact is that there are several important aspects of these devices that are not well understood. One of these issues is the interaction between the electrons and the magnetic field. While they are commonly assumed to follow field lines perfectly [1], this cannot be the case in practice, as they will inevitably return to the thruster and negate the ambipolar electric field that accelerates the ions. The question then remains as to if and how they can travel across field lines.

While several theories have been proposed to explain electron cross-field transport in magnetic nozzles [2], this work focuses on the role of instabilities. As instabilities grow, they induce an effective drag on the electrons, allowing transverse motion. While we have previously investigated the role of an incoherent azimuthal mode [3], we have also observed a series of lower frequency, coherent modes that exist in the plume (Fig. 1). In this work, we focus on these modes, explaining them theoretically using linear kinetic theory. Furthermore, we quantify their impact on electron transport by defining an effective collision frequency with quasilinear theory. We have taken this approach in the past in determining the impact of the incoherent mode, and it is commonly taken in literature to describe the impact of instabilities on electron transport. We compare this impact on electron motion to that induced by the incoherent mode.

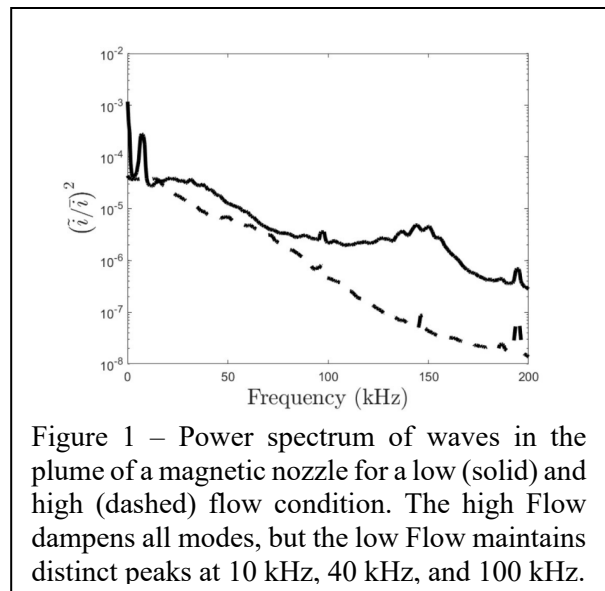


Figure 1 – Power spectrum of waves in the plume of a magnetic nozzle for a low (solid) and high (dashed) flow condition. The high Flow dampens all modes, but the low Flow maintains distinct peaks at 10 kHz, 40 kHz, and 100 kHz.

* This work is funded under NASA Space Technology Research Fellowship grant number 80NSSC17K0156.

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Ni-lined Capsules as Backlighters for Multiple Measurements in High-energy-density Physics Experiments*

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Capsule implosions are bright sources of continuum x-rays that are used in high-energy-density (HED) experiments for absorption measurements. It is common in HED experiments to have a single primary measurement, which limits the amount of information one can extract out if the already limited available experiment time. An x-ray source with useful continuum and line emission would allow for the combination of absorption measurements and scattering or fluorescence measurements.

To accomplish this, a plastic (CH) capsule had a layer of Ni on the interior surface. This will create a hot, dense Ni plasma that will produce bremsstrahlung emission. The Ni plasma will also have an optically thin layer at the outer surface that will allow line emission to escape. The CH layer is 7 μm thick, the Ni layer is 0.2 μm thick, and the outer diameter of 870 μm . This design has the same mass as standard CH capsules at the Omega laser facility at the laboratory for laser energetics, which means the Ni capsules should have similar implosion characteristics. Radiation hydrodynamics experiments in the HELIOS-CR 1D Lagrangian code confirm this.

Recent experiments demonstrated the effectiveness of Ni-lined capsules for use in experiments. Time-integrated spectra show the continuum spectra in the 2-4 keV range and the Ni line emission in the 5-8 keV. The data shows strong continuum emission and some line emission, which is a promising first result with this new capsule design. Comparisons of the data to simulations shows good agreement with the timing of the x-ray flash.

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Optimized Spectroscopic Measurement of High Energy, Narrow Energy-Spread Electron Beams from a Laser Wakefield Accelerator*

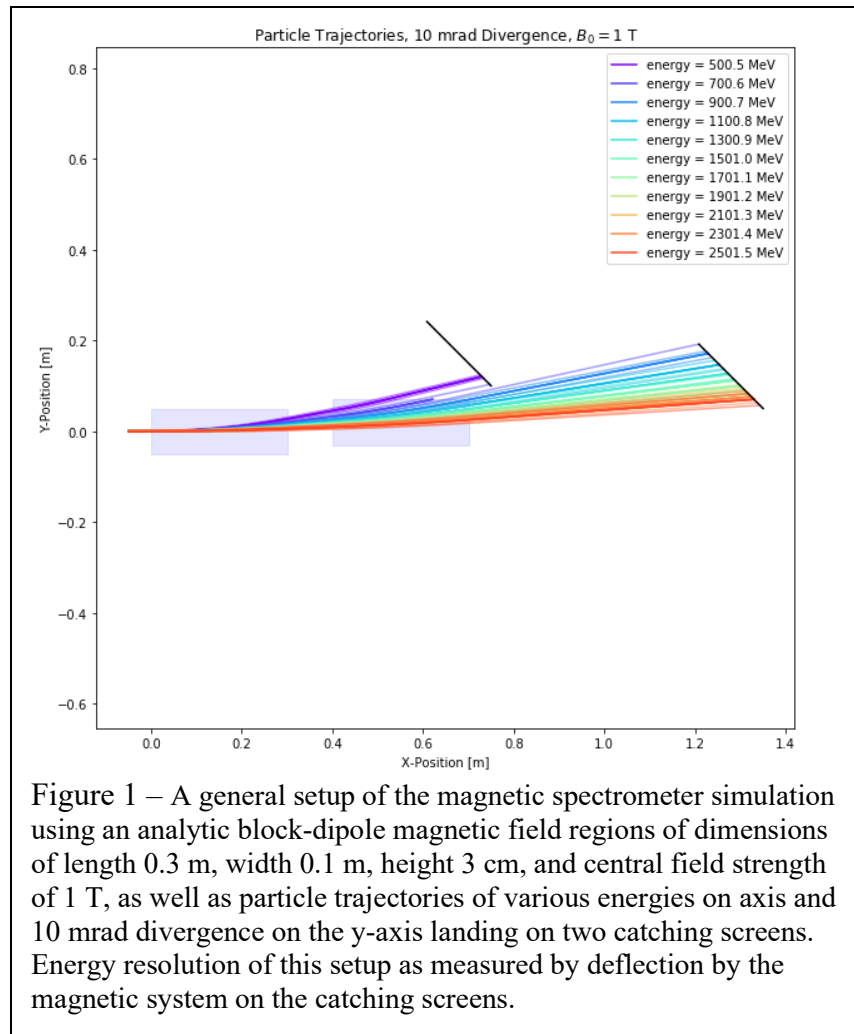
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A continuing goal of laser wakefield acceleration (LWFA) research is to decrease the spread in energy of the electron beams that these accelerators can produce while simultaneously increasing the maximum central energy of these beams. High-energy mono-energetic beams are a requirement for most applications of LWFA including using accelerated beams as light sources, or as a probe for fast-evolving fields. These beams present a particular challenge to accurately measure in the laboratory due to the standard dipole electron spectrometer's decrease in energy resolution as particle energies increase.

In this work, it is demonstrated through PIC simulations of various LWFA injection mechanisms that high-energy (in excess of 1 GeV) electron beams with low energy spread (a few percent) are produced using modern laser parameters and feasible experimental setups. These beams are then computationally measured using a simulated magnetic spectrometer. It is shown that a genetic algorithm approach may be applied to the configuration of the spectrometer's

magnets and phosphorus screens to optimize energy resolutions in the energy range we are interested in. As LWFA beam energies continue to climb, further optimization of spectrometer techniques will be increasingly important.



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PlasmaPy for HEDP Regime*

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PlasmaPy is a Python package being developed to foster an open source software ecosystem focused around plasma physics research and education. The high-energy-density (HED) physics regime refers to systems with an energy density >1 Mbar or 10^6 atm. In this regime, plasmas behave differently from ideal plasmas and require additional functionality to describe them. For example, ionization, magnetic fields, and relativity can be important in this regime. I am tasked with adding functionality to PlasmaPy that is relevant to HED plasma physics. One such function is the magnetic Reynolds number (R_m): which is the ratio of magnetic induction to diffusion in a conducting fluid, where a large R_m indicates an ideal magnetohydrodynamic (MHD) fluid and a small R_m indicates a resistive MHD or that this fluid is in the diffusive limit. Another example is the Saha equation: which estimates the ratio of ions of a plasma in one ionization state to those in another. This becomes more accurate in the HED regime. Relativistic particles are also more abundant in the HED regime therefore relativistic functions are needed. Future efforts will be to add functionality for processing and analyzing data from experimental facilities such as the ZEUS laser in Michigan.

* This work is funded by the U.S. Department of Energy NNSA Center of Excellence under cooperative agreement number DE-NA0003869 and NSF CSSI awards 1931388 and 1931429.

Uncertainty Quantification and Credible Predictions for Reduced-Fidelity Modeling of Porous Electrospray

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Uncertainty in the parameters of several reduced-fidelity models for porous electrosprays is quantified using Bayesian inference. Particularly, three models employed by the Electrospray Propulsion Engineering Toolkit (ESPET), a reduced-modeling framework for propulsive electrosprays, are examined [1]. 1) The model of Coffman et al. predicting ion current in the pure-ionic emission regime (PIR) [2]. 2) The scaling of Gañan-Calvo et al. for jet current in the cone-jet emission regime [3]. 3) The empirical model of St. Peter et al. for the number of active emission sites as a function of applied voltage [1]. Parameters are learned using experimental data available in the literature, yielding posterior distributions over parameter space (see Fig. 1). Inferred model parameters are compared within deterministic values previously reported and agree within an order of magnitude. Probabilistic performance predictions with credible intervals for a real electrospray emitter are then made using the inferred parameters and the ESPET QuickSolver. These predictions are found to underestimate the experimentally measured current of the emitter by about a factor of 3 across the domain, and the pure-ionic emission scaling is discussed as a cause. The inference is updated by incorporating the “new” experimental data. It is found that the ionic current scaling parameter changes much more significantly than the other parameters, supporting it as the primary source of disagreement. Additional predictions are then made excluding the original PIR data (see Fig. 2). Potential lack of applicability between different propellants and the role of model parameters (e.g. emitter geometry) that were taken as certain for this analysis (but may in fact be significantly uncertain) are discussed. The methodologies employed are examined within the context of a novel development strategy for electrospray thrusters that combines the ESPET reduced-fidelity modeling framework and rapid prototyping in a robust design optimization loop.

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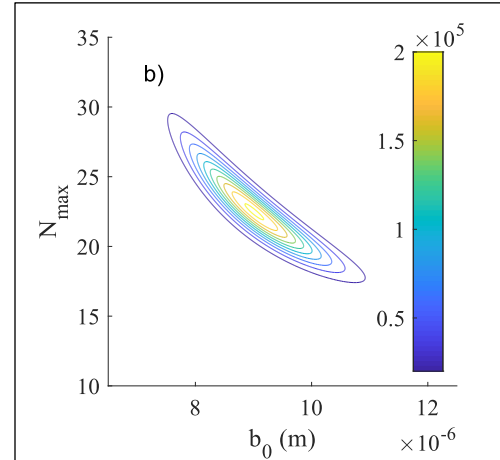


Figure 1 – Joint posterior distribution of parameters b_0 and N_{max} of the empirical model for number of emission sites as a function of voltage [1,4].

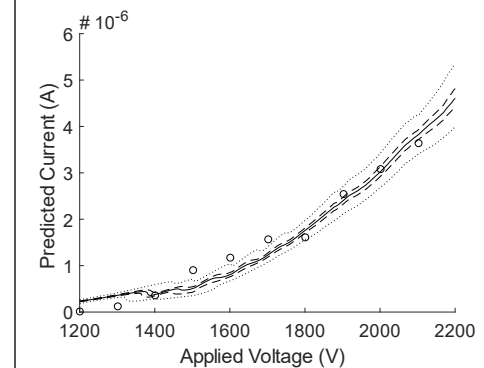


Figure 2 – Probabilistic performance predictions for emitter current as a function of applied voltage with credible intervals (solid: median, dashed, 33rd and 66th percentile, dotted: 2.5th and 97.5th percentile), compared with experimental data (circles) [1,4].

Using Auroras to Investigate the Geospace Magnetic Topology

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The Earth's magnetic field is roughly a dipole out to about geostationary distance (6.6 Earth Radii or 42,000 km). The magnetic bottle created by the dipole field traps energetic electrons and protons, which circle around the Earth in addition to their bounce motion between the mirror points. In the direction away from the Sun (the “nightside”), interaction with the solar wind stretches the Earth's dipole field into a long magnetotail similar to that of cometary tails. However, though stretched, the magnetotail field is still topologically similar to the dipole field, and the trapped particles can only gain access to the atmosphere by leaking through the loss cone. The precipitation into the loss cone is what creates the auroral oval, which then is a visual representation of the magnetic bottle at atmospheric end.

However, there are periods when the auroral oval topology splits into two, forming a large “theta” orientation. The “theta bar” is seen to grow from the nightside (lower left) toward the day-side (top right) until the polar cap within the oval is completely split into two. The theta bar then moves eastward and finally merges with the oval again. It is a long-standing question how this pattern is connected with the magnetotail, as simple topological argument would suggest similar splitting of the magnetotail.

We investigate the theta aurora phenomenon by using a global MHD simulation to model the solar wind – magnetosphere – ionosphere system for the duration of the theta aurora. With the simulation, we can trace the field lines to map the locations of the theta aurora to the magnetotail to resolve the origin of the particles creating the unusual auroral shape. The model results are validated by comparing them with the global auroral satellite images.

