Seeding and Evolution of Magnetohydrodynamic Instabilities of a Metal Surface Driven by Intense Current*

Project Start: October, 2018

Co-PI’s: M. Gilmore\textsuperscript{a}, B. Bauer\textsuperscript{b}, B. Srinivasan\textsuperscript{c}
Students: M. Hatch\textsuperscript{a}, T. Hutchinson\textsuperscript{b}, A. Klemmer\textsuperscript{b}, S. Kreher\textsuperscript{b}, R. Masti\textsuperscript{c}, K. Todd\textsuperscript{b}
Collaborators: K. Yates\textsuperscript{d}, T. Awe\textsuperscript{e}, E. Yu\textsuperscript{e}, I. Lindemuth\textsuperscript{b}, S. Patel\textsuperscript{e}, R. Reinovsky\textsuperscript{d}, C. Rousculp\textsuperscript{d}

\textsuperscript{a}University of New Mexico, \textsuperscript{b}University of Nevada, Reno, \textsuperscript{c}Virginia Tech, \textsuperscript{d}Los Alamos National Laboratory, \textsuperscript{e}Sandia National Laboratories

*Supported by NNSA Stewardship Sciences Academic Programs under award numbers DE-NA0003870, DE-NA0003872, and TBD
# Personnel and National Lab Interactions

## Students and Post Docs

<table>
<thead>
<tr>
<th>Name</th>
<th>Affiliation</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maren Hatch</td>
<td>PhD student</td>
<td>UNM</td>
</tr>
<tr>
<td>Trevor Hutchinson</td>
<td>PhD candidate</td>
<td>UNR</td>
</tr>
<tr>
<td>Aidan Klemmer</td>
<td>PhD student</td>
<td>UNR</td>
</tr>
<tr>
<td>Seth Kreher</td>
<td>PhD student</td>
<td>UNR</td>
</tr>
<tr>
<td>Robert Masti</td>
<td>PhD candidate</td>
<td>VA Tech</td>
</tr>
<tr>
<td>Kelby Todd</td>
<td>Undergrad. student</td>
<td>UNR</td>
</tr>
<tr>
<td>Post-Doc (TBD)</td>
<td></td>
<td>UNM</td>
</tr>
</tbody>
</table>

## Faculty

<table>
<thead>
<tr>
<th>Name</th>
<th>Affiliation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bruno Bauer</td>
<td>UNR</td>
</tr>
<tr>
<td>Mark Gilmore</td>
<td>UNM</td>
</tr>
<tr>
<td>Bhuvana Srinivasan</td>
<td>VA Tech</td>
</tr>
</tbody>
</table>

## No-Cost Collaborators

<table>
<thead>
<tr>
<th>Name</th>
<th>Institution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tom Awe</td>
<td>SNL</td>
</tr>
<tr>
<td>Irv Lindemuth</td>
<td>UNR</td>
</tr>
<tr>
<td>Sonal Patel</td>
<td>SNL</td>
</tr>
<tr>
<td>Rob Reinovsky</td>
<td>LANL</td>
</tr>
<tr>
<td>Chris Rousculp</td>
<td>LANL</td>
</tr>
<tr>
<td>Kevin Yates</td>
<td>LANL</td>
</tr>
<tr>
<td>Edmund Yu</td>
<td>SNL</td>
</tr>
</tbody>
</table>

* Performing/will perform PhD or post-doctoral research on site at SNL
** Performing PhD research on site at LANL
1. To understand the seeding, formation, and evolution of the Electro-Thermal Instability (ETI) in a thick wire regime in the solid, liquid, vapor, and plasma phases

2. To understand the seeding of late time MHD instabilities via early time ETI

3. To understand the effect of hydrodynamics on the growth rate of ETI and the formation of plasma

4. To understand the development of azimuthal correlation of MHD instabilities

5. Through numerical effort, deepen the understanding of metal driven by intense current and of the influence of various modeling assumptions

6. Educate students in high energy density (HED) laboratory plasma physics and train them in experimental and numerical methods for working with magnetized HED plasma
MHD Modeling Shows Development of Experimentally-Observed Strongly Azimuthally-Correlated MRT Structures When an Initial Liner Perturbation is Included

- Liner (Al or Be)
- Cold DT gas (fuel)
- Azimuthal drive field
- Axial magnetic field
- Preheated fuel
- Laser beam
- Compressed axial field

MAGLIF

McBride et al., PRL 109, 135004 (2012)
**Motivation/Approach**

**Question:** Does nonuniform Joule heating provide the seed for Magneto-Rayleigh-Taylor (MRT) instability growth in magnetically-driven, solid liner implosions?

- **Nonuniform Joule Heating of Solid Liner** → **Electrothermal Instability (ETI)** → **Azimuthally-correlated structures** → **Seed for MRT?**
  
  - **Nonuniform Implosion**

- We will investigate (continue to investigate) the detailed physics of ETI evolution in a simplified geometry on a well-diagnosed, 1 MA-scale driver, using defect-controlled loads, together with 3D MHD simulations.
Electrothermal instabilities are driven by Joule heating and arise when resistivity ($\eta$) depends on temperature ($T$).

Simulations detail how current redistribution drives ETI.

Isolated pits merge to form striations.

Allegra simulations by E. Yu, SNL.

- Current bends around pits or resistive inclusions, driving enhanced Joule heating and $T$ at edge, thus locally reducing the conductivity. This effectively widens the perturbation; in this way neighboring perturbations merge.
Electrothermal instability can occur when material resistivity $\eta$ depends on temperature $T$ or density $\rho$

Condensed metals form strata $\perp \mathbf{j}$

$$\frac{d\eta(T)}{dT} > 0$$

Plasmas form filaments $\parallel \mathbf{j}$

$$\frac{d\eta(T)}{dT} < 0$$

For conductors thicker than electrical skin depth, ETI can be undermined by diversion of $\mathbf{j}$ around resistive (e.g., low density or high $T$) regions

ETI Studied Previously Using 6061 Al “Thick Wires” on Zebra and MYKONOS by UNR/SNL

Barbell-shaped thick wire geometry (Zebra)

16 Frame Imaging Shows Bright Dots Evolve Into Filaments

- > 5 \( \mu \)m defects appear to seed hot spots
- Hot spots evolve into filaments
- 6061 Al: > 100 5 \( \mu \)m defects /mm\(^2\)
New Experiments Will Utilize Engineered Defect Loads and Have Improved Diagnostics

- High purity Al (99.999%) barbell with discrete, engineered (machined) defects

- New high resolution, multi-frame, multi-angle visible imaging and shadowgraphy

- Imaging resolution goal: 1 μm, < 2 ns
Experiments Will Be Conducted on the MYKONOS-V 1 MA Driver at SNL

- Five stage Linear Transformer Driver (LTD) voltage adder
- 1 MA
- 500 kV pulse
- Rise time (10%-90%) ~ 80 ns (barbell load)
- Pulse width (FWHM) ~ 160 ns
Numerical Modeling at Virginia Tech: MHD models with SESAME EOS (USIM and FLASH)

- Virginia Tech has developed some expertise performing simulations of the electrothermal instability with SESAME EOS, and Lee-More-Desjarlais electrical and thermal conductivities

- Conditions Needed for ETI
  - Current
  - Positive Feedback:
    - Resistivity
    - Joule Heating
  - Thermal Conduction effects on ETI

Preliminary simulations of ETI growth in Aluminum

Simulations performed in MagLIF-relevant regimes
S.E. Kreher (UNR) modeling with LANL-FLAG

✓ Los Alamos National Lab magnetohydrodynamics code FLAG
  - 1/2/3 Dimensions
  - Radiation MHD
  - Strength Model
  - Arbitrary Lagrangian-Eulerian hydrodynamics

✓ SESAME EOS & Conductivity
  - Scalar tabular references (potential for tensor lookups)
  - Desjarlais, Garanin, and Starrett conductivity table comparisons

✓ LANL Snow HPC cluster
  - 13,248 nodes/47.1 TB memory

FLAG output of Exploding Wire on ZEBRA
Density (left) in g/cc, Temperature (right) in K

Status and Plans

- Engineered-defect “barbell” rod loads are currently being fabricated by General Atomics.
- Improved resolution (Goal: 1 µm), multi-frame, multi-angle visible imaging using up to 4 cameras for experiments on MYKONOS is under development.
- Multi-frame, multi-angle laser-based shadowgraphy is in development by UNM and SNL jointly.
- Engineered defect load experiments will begin this summer. Experiments on dielectric-coated rods (UNR/SNL) and self-magnetizing liners (“Automag” – SNL/UNM) will be continuing.
- Present development done in collaboration with Tech-X in code USIM and with Univ. of Chicago using the FLASH code.
- MHD simulations will be performed for parameters of relevance to the proposed Mykonos experiments.
- Experimental data will be used for code validation studies.
- The focus would be to understand the early-time ETI growth and to follow its development into late-time MHD instabilities.
- Five U.S. citizen PhD students (3 working on site at SNL, 1 working on site at LANL) and one Post-Doc (TBD) are/will be fully supported.