Exploration of Magnetic-Field Generation via Biermann Battery Using the FLASH Code to Model Experiments Performed at UCLA’s Phoenix Laboratory

Marissa B. P. Adams*
Flash Center for Computational Science
Department of Physics & Astronomy, University of Rochester
* madams15@ur.rochester.edu

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Acknowledgments

P.-A. Gourdain, P. Tzeferacos
Department of Physics & Astronomy, University of Rochester

S. Feister
Department of Computer Science, California State University, Channel Islands

J. J. Pilgram, C. G. Constantin, C. Niemann
Department of Physics and Astronomy, University of California, Los Angeles

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How are magnetic fields generated?

\[ \dot{B} \propto \nabla T_e \times \nabla n_e \]

e.g., Biermann Battery (L. Biermann (1950));

How may laser-target illumination aid us in understanding this?
UCLA’s Phoenix Lab has measured Biermann Fields at the centimeter scale!

Figure: Side-on perspective of the UCLA Phoenix Laboratory’s experimental set-up using the Peening and Thomson scattering beams (c:JJP)
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Figure: Distance from the laser spot vs $t$ at which the maximum $B_\theta$ occurred (black) for $x = -0.7$ cm and $x = 0$ cm. Linear fit (blue line) was applied showing an estimated $v \sim 330$ km/s (c:JJP)
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**Figure:** Side-on perspective of the UCLA Phoenix Laboratory’s experimental set-up using the Peening and Thomson scattering beams (c:JJP)

- PhD Candidate **Jessica J. Pilgram (JJP)** (PI: C. Niemann) carried out these experiments!
- She gave this year’s HEDSA Student Talk on Sunday!
- **Visit her poster!** (NP11.00160) Wednesday, November 10, 2021, 930-1230 in Exhibit Hall A 🖼️

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We use FLASH simulations to understand the physical processes!

M. B. P. Adams  
Biermann Battery Validation with FLASH
The FLASH Code

- FLASH is a publicly available, high performance computing (HPC), adaptive mesh refinement (AMR), finite-volume, hydro and MHD code with extended physics capabilities. Supported primarily by the U.S. DOE NNSA. (Fryxell+2000, Tzeferacos+2015)
- FLASH is professionally managed software in continuous development for 20 years: coding standards; version control; daily automated regression testing; extensive documentation; user support; integration of extensive code contributions from external users.

> 3,500 users worldwide

> 1,200 papers published with FLASH

Visit https://www.flash.rochester.edu & download FLASH today! 👉

Courtesy of P. Tzeferacos
How are we using FLASH?
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How are we using FLASH?

- Initializing 2D Cartesian geometry of target with laser-facing side in xy-plane
- (maximum) 20 J laser modeled with a triangle wave with a peak power of $1.3 \times 10^9$ W at 7.5 ns for a 15 ns duration pulse
- Note closest corresponding planes of measurement $x = -0.7$ cm and $x = 0$ cm
- Biermann source on for whole simulation (Full BB) and only for laser duration (LOBB)
How are we using FLASH?

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**Goals:**
- Elucidate upon the laser produced plasma’s material properties
- Calibrate, and determine the Peening laser’s intensity
- Validate the Biermann source-term implementation in the FLASH code
Biermann generation in the plume is important!

Figure: An animation of the magnetic field evolution from a Peening laser produced plasma (LPP); Biermann battery term is calculated (a) for the duration (15 ns) of the laser’s pulse only (LOBB) and (b) for the full (Full BB) simulation duration (400 ns).
FLASH can also provide the plasma properties

Figure: For $t = 150$ ns (a) the electron density in $\text{cm}^{-3}$, (b) the electron temperature in eV, (c) the plasma’s velocity in $\text{km s}^{-1}$ and finally (d) the Magnetic Reynolds number

Calibrated 2D simulations are being performed to match $\nu$ of the fields, their values, as well as the plasma properties
Concluding Remarks

- The DOE Center of Excellence **Center for Matter Under Extreme Conditions** has provided a great infrastructure for student led collaborations such as this one!

- The goal of this work is to understand the physics that occurred in JJP’s experiments using validated FLASH simulations
  - The magnetic field topology
  - The material properties of the laser produced plasma
  - and the laser’s intensity!

- High fidelity 3D FLASH simulations will be used to understand what is physically happening in the experiment

- Calibrated 2D FLASH simulations are underway; with experimental results, be used to validate the Biermann implementation in the code by using their experimentally obtained values \((n_e, T_e, \nu, B_\theta)\)

- **Visit Jess’ poster! (NP11.00160) Wednesday, November 10, 2021, 9:30-12:30 in Exhibit Hall A**

Thank you for your time and attention! 👏