Investigations of Relativistic Laser Driven Reconnection using OMEGA EP

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Magnetic fields in plasmas can strongly influence the dynamics and are important in many HEDP laboratory and astrophysical plasmas.

**ICF**

A Joglekar, et al., PRE, 93, 043206 (2016)

**Solar wind and planetary fields**

PY Chang, et al., PRL, 107, 035006 (2010)

A Joglekar, et al., PRE, 93, 043206 (2016)

**MAGLIF**


G Fiksel, et al., PRL, 113, 105003 (2014)

**AGN: Active galactic nuclei**

**GRB: Gamma ray bursts**
This Omega EP campaign has studied …

**Picosecond B-field (different Z targets)**

- Aluminum
- Copper
- Plastic

**The interaction ns and ps B-fields**

**Nanosecond B-field (different Z targets)**

**The interaction ps B-field with obstacles**
Laser generated magnetic fields

Nanosecond pulses, $I \sim 10^{14} \text{ Wcm}^{-2}$
$B \sim 1 \text{ MG}$
$\nu_B \sim 10^5 \text{ ms}^{-1}$

Picosecond pulses, $I \sim 10^{19} \text{ Wcm}^{-2}$
$B \sim 100 \text{ MG}$
$\nu_B \sim c$

\[ \frac{\partial B}{\partial t} = \frac{k_B}{en_e} \nabla T_e \times \nabla n_e \]

JA Stamper and BH Ripen, PRL, 34, 138 (1975);
CK Li, et al., PRL, 97, 255001 (2006)

W. Schumaker et al. PRL, 110, 015003 (2013)
G. Sarri et al. PRL, 110, 255002 (2013)
A. E. Raymond et al. PRE, 98, 043207 (2018)
Particle-in-cell simulations illustrate the magnetic field generation, dynamics and characteristics

\[ \sigma_{\text{cold}} = \frac{B^2}{\mu_0 n_e m_e c^2} \]

(Osiris simulations performed by Paul Campbell as part of this project)
Simulations show the magnetic energy can exceed the rest mass energy to access a new regime in the laboratory.

\[ \sigma_{\text{cold}} = \frac{B^2}{\mu_0 n_e m_e c^2} \]

AGN: Active galactic nuclei

GRB: Gamma ray bursts

XBD: X-ray binary disk coronae

\[ \sigma = 10^3 \]

High-intensity

\[ \sigma = 10^6 \]

ns laser-plasma

MRX

Laser-driven magnetic reconnection

Moderate intensity (ns)

P.M. Nilson et al. PRL, 97, 255001 (2006)

High intensity (ps)

A. E. Raymond et al. PRE, 98, 043207 (2018)

We use one of the OMEGA EP relativistic intensity laser pulses to provide a proton probe diagnostic of the EM fields.

Radiochromic film (RCF) stack

Cu target

Time-of-flight

IR short pulse
500J, 10ps, $10^{19}$ W/cm²

IR short pulse
150-300J, 1ps, 2.5 - 5$x10^{19}$ W/cm²
The proton probe provides information about the temporal dynamics. Time-of-flight graphs and images show the evolution of the event at different times: t = 0 ps, t = 6.5 ps, t = 11.3 ps, t = 18 ps, t = 22.8 ps, t = 26.9 ps.
The proton probe provides a measurement of the path integrated magnetic field strength.
The proton probe provides a measurement of the path integrated magnetic field strength

\[ t = 6.5 \text{ ps} \]

1D radiography inversion

2D radiography inversion

Inversion code based on an iterative solution of the nonlinear Poisson equation

Nanosecond B-fields: 1250 J, 1 ns, d = 0.8 mm

Previous work:

Collaborators have simulations in progress…
Proton radiography of a highly asymmetric magnetic reconnection geometry


UV long pulse
1250J, 1ns, 2x10^{14} W/cm^2

IR short pulse
500J, 10ps, 10^{19} W/cm^2

IR short pulse
300J, 1ps, 5x10^{19} W/cm^2

Cu, Al, or CH target

Radiochromic film (RCF) stack

8, 7.8 cm

6, 8 mm
Proton radiography of a highly asymmetric magnetic reconnection geometry

UV long pulse

IR short pulse

[Images of proton radiographs for copper, aluminum, and plastic]
2D proton radiograph inversions of the asymmetric geometry

$t = 0\ \text{ps}$

$t = 11.3\ \text{ps}$
3D Osiris particle-in-cell simulations of the asymmetric geometry

Plasma density evolution

Density slice at $z=0$ $c/\omega_p$

Hot electrons

“Cold” plasma

Density slice at $y=50$ $c/\omega_p$
3D Osiris particle-in-cell simulations of the asymmetric geometry

Magnetic field Evolution

$B_z$ slice at $z = 0 \ c/\omega_p$
3D Osiris particle-in-cell simulations of the asymmetric geometry

“Cold” plasma bubble electrons
Magnetic field dynamics around obstacles

Holes laser machined through foils

Glue “blobs”

$\phi = 25 \mu m - 500 \mu m$

Proton radiographs

Field inversion and particle-in-cell simulations are in progress
We have

- Performed experiments studying
  - Picosecond B-field (different Z targets)
  - Nanosecond B-field (different Z targets)
  - An asymmetric reconnection geometry
  - The interaction ps B-field with obstacles

- Developed a 2D inversion code for the proton probe diagnostic

- Performed 2D and 3D particle-in-cell simulations to investigate the physics

Publications in preparation:
- P Campbell, et al., Target material effects on the generation and dynamics of laser-driven magnetic fields (2019)
- P Campbell, et al., Asymmetric, laser driven magnetic interactions (2019)
- P Campbell, et al., Pulse duration effects on laser driven proton acceleration (2019)

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- Brandon Russell, GSRA

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