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MHD Simulation of Flare Experiment

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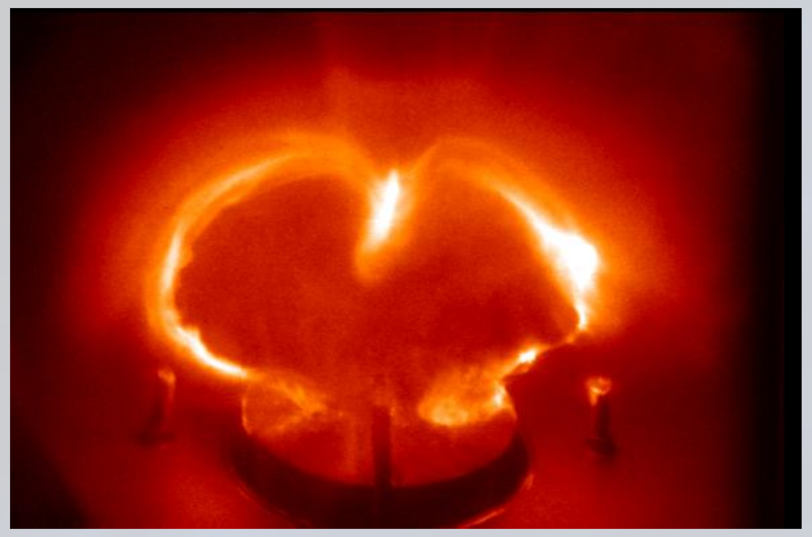
Introduction

- Simulation of a future plasma flare experiment similar to prior setups at Caltech [1], Ruhr-Universität Bochum, Germany [2] and PPPL [3]
- Used massively parallel two-fluid code `F3D` [4] running on Franklin and Hopper supercomputers at NERSC
- Goal to provide computational support for experiment intended to study magnetic reconnection and particle acceleration



Plasma gun developed by the Bellan Group at Caltech [1]

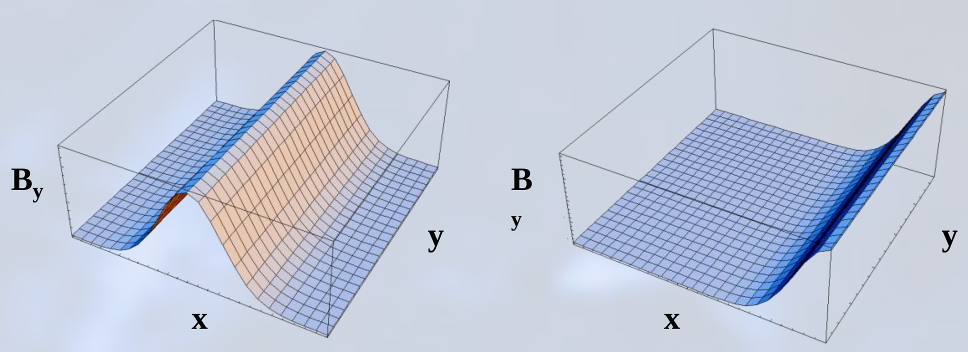
Model

Magnetohydrodynamics (MHD):

$\frac{\partial \rho}{\partial t} + \nabla \cdot \rho \mathbf{v} = 0$	Continuity	$\nabla \cdot \mathbf{B} = 0$	No monopoles
$\rho \left(\frac{\partial \mathbf{v}}{\partial t} + \mathbf{v} \cdot \nabla \mathbf{v} \right) = \frac{\mathbf{J} \times \mathbf{B}}{c} - \nabla p$	Momentum	$\mathbf{J} = \nabla \times \mathbf{B}$	Ampères Law
$\frac{\partial \mathbf{B}}{\partial t} = \nabla \times (\mathbf{v} \times \mathbf{B})$	Faraday's Law	$\mathbf{E} = -\frac{\mathbf{v} \times \mathbf{B}}{c}$	Ohm's Law

Boundary Conditions:

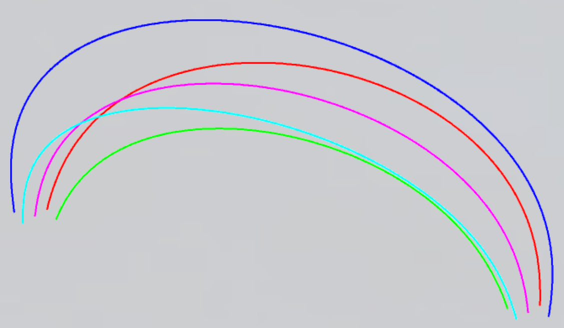
- Model perfectly conducting box by using guard-cells outside simulation domain
- Dirichlet & Neumann BC's on walls
- Tests: Initial conditions that violate BC's & Alfvén wave reflection



A test for conducting boundary conditions: Send a single Alfvén wave packet toward conducting wall and observe reflection

Initial Magnetic Field Lines:

- Superposition of electromagnet and current loop tailored to meet boundary conditions



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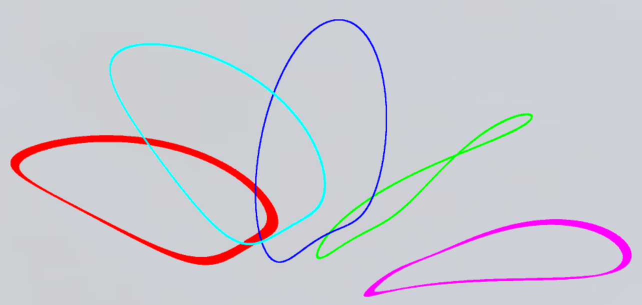

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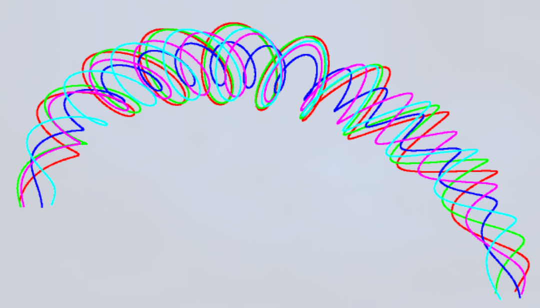
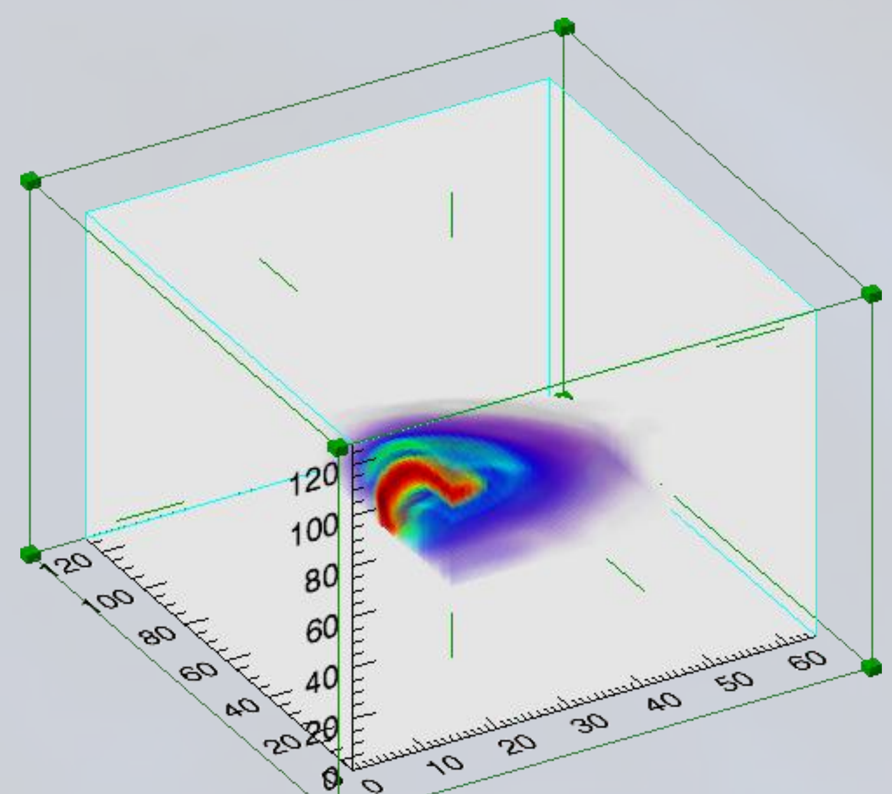


Electromagnet　Current Loop　Superposition

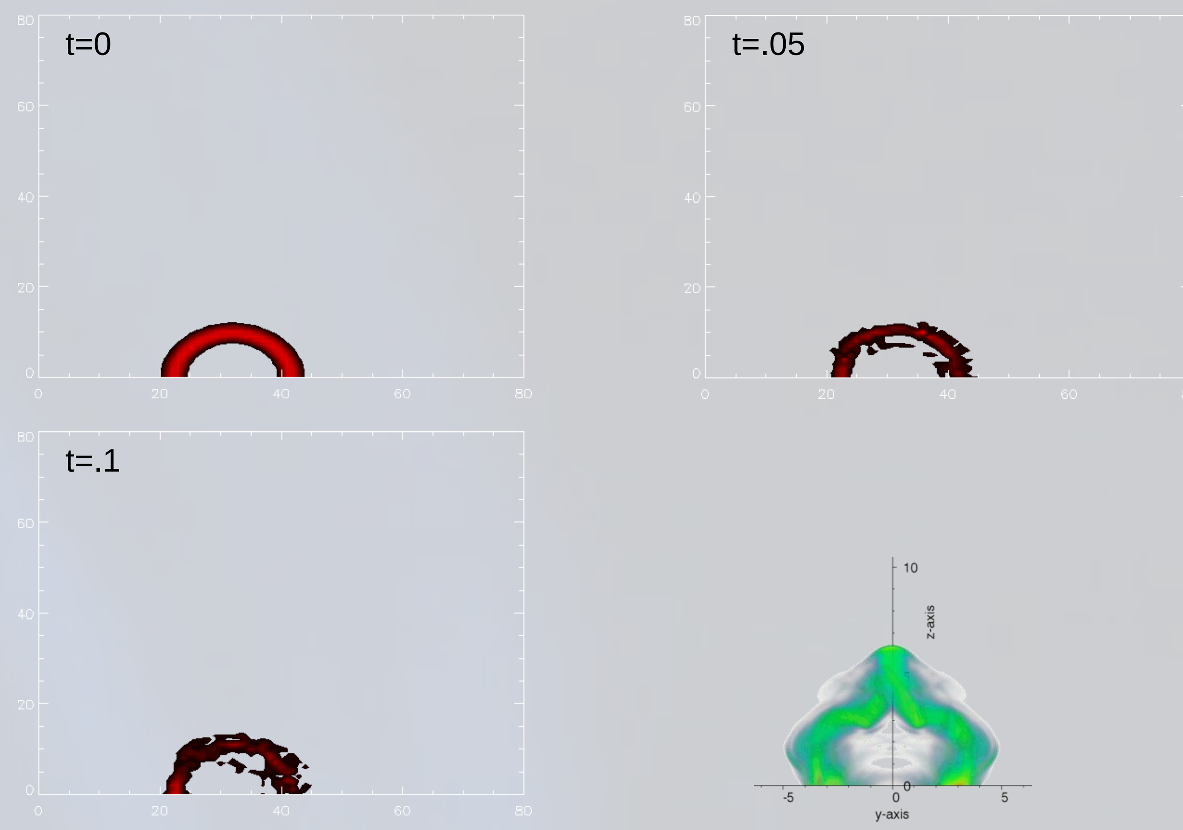
Simulation

- Calculations done on Franklin, a 38,288 core, 352 TFlop/sec supercomputer (very small fraction of this computing power required for present task)
- MHD codes are sensitive to numerical effects such as the Courant condition and numerical resistivity
- Higher resolution simulations to capture true physics are underway

NERSC's Franklin Cray XT4 supercomputer



Cross section of simulated current density



Example of current loop disintegration in a 64 x 64 x 16 grid-point simulation domain. At the lower right is the desired Ideal MHD evolution from Ref. [2].

Conclusions

- `F3D` has been extended to model expanding magnetic flux loops in a conducting cavity
- MHD is a useful tool for understanding and designing laboratory flare experiments

Future Work

- Perform high resolution simulations
- Incorporate Hall term to better model magnetic reconnection
- Expand simulation to include multiple flux loops and alternate initial conditions
- Use `F3D` along with the experiment to gain deeper physical insight

Acknowledgments:

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[1] P.M. Bellan and J.F. Hansen, Physics of Plasmas, 5, 1991 (1998).

[2] L. Arnold, J. Dreher, R. Grauer, H. Soltwisch and H. Stein, Physics of Plasmas, 15, 2008

[3] N. Williams, E. Oz, M. Yamada, H. Ji, S. Dorfman, B. McGeehan, and J. Schroeder, <http://meetings.aps.org/link/BAPS.2008.DPP.JP6.39>

[4] M. A. Shay, J.F. Drake, M. Swisdak and B.N. Rogers, Physics of Plasmas, 11, 2004

* Background image from Transition Region and Coronal Explorer (TRACE) Satellite, NASA/GSFC, 26 September 2000