Extended MHD modeling of nonlinear instabilities in fusion and space plasmas

Final Technical Report

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Project Title:	Extended MHD modeling of nonlinear instabilities in fusion and space plasmas
Project Director / Principal Investigator:	Kai Germaschewski
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Abstract

A number of different sub-projects where pursued within this DOE early career project. The primary focus was on using fully nonlinear, curvilinear, extended MHD simulations of instabilities with applications to fusion and space plasmas. In particular, we performed comprehensive studies of the dynamics of the double tearing mode in different regimes and configurations, using Cartesian and cyclindrical geometry and investigating both linear and non-linear dynamics. In addition to traditional extended MHD involving Hall term and electron pressure gradient, we also employed a new multi-fluid moment model, which shows great promise to incorporate kinetic effects, in particular off-diagonal elements of the pressure tensor, in a fluid model, which is naturally computationally much cheaper than fully kinetic particle or Vlasov simulations.

We used our Vlasov code for detailed studies of how weak collisions effect plasma echos. In addition, we have played an important supporting role working with the PPPL theory group around Will Fox and Amitava Bhattacharjee on providing simulation support for HED plasma experiments performed at high-powered laser facilities like OMEGA-EP in Rochester, NY.

This project has support a great number of computational advances in our fluid and kinetic plasma models, and has been crucial to winning multiple INCITE computer time awards that supported our computational modeling.

Project Summary

Double tearing mode evolution in cylindrical and Cartesian geometry

Reversed-shear tokamak designs have been shown to have beneficial properties over conventional configurations. Shifting the plasma current from a single axial channel to an annulus surrounding the core avoids certain classes of instabilities and may provide better confinement. Observations in TFTR, NSTX, Tore Supra, and other reverse shear plasmas, however, show 'off-axis sawtooth' disruptions of the annular ring. One candidate instability for these disruptions is the double-tearing mode (DTM), wherein two nearby rational surfaces couple and reconnect. Linearly the two surfaces drive each other, resulting in a faster growing instability than the standard tearing mode[1, 2]. Continued nonlinear growth of the DTM leads to an explosive generation of kinetic energy and destruction of the current ring[3]. Understanding the DTM evolution, and it's potential for disruption, may therefore be an important factor in future reverse-shear devices.

The key to stabilizing the double-tearing mode lies in suppressing the coupling between the two tearing unstable rational surfaces, as their interaction is the source of the DTM's volatility. Recent slab Cartesian simulations[4] have shown that linearly the two tearing surfaces can be separated by a sufficiently high differential equilibrium flow. The growth rate of the decoupled modes is less than the static DTM, but does not decrease further at larger flow amplitudes. This sheared-flow driven mechanism also results in the emergence of Alfvén resonance layers which couple to the (now drifting) tearing surfaces and can again increase the growth rate. Similar flow driven mechanisms may be a tool for slowing the nonlinear growth of the magnetic islands, however the required shears may cause the plasma to be unstable to Kelvin-Helmholtz instability.

Using the Hall MHD simulation code `MRCv3` we have investigated the DTM stabilization potential of equilibrium diamagnetic drifts, which have several advantages over bulk plasma flows. Local the the tearing layer diamagnetic effects interfere with the reconnection process, decreasing the growth of the mode. This ω_* mechanism is known to be strongly stabilizing for the $m = 1$ kink-tearing mode, for which nonlinear enhancements of the pressure gradient may result complete saturation of the instability and finite sized magnetic islands[5]. Furthermore, reversed magnetic shear configurations frequently feature steep density and temperature profiles associated with of internal transport barriers (ITBs). The resultant pressure gradients may, therefore, cause differential diamagnetic rotation in the neighborhood of the DTM unstable surfaces that can decouple and stabilize the modes.

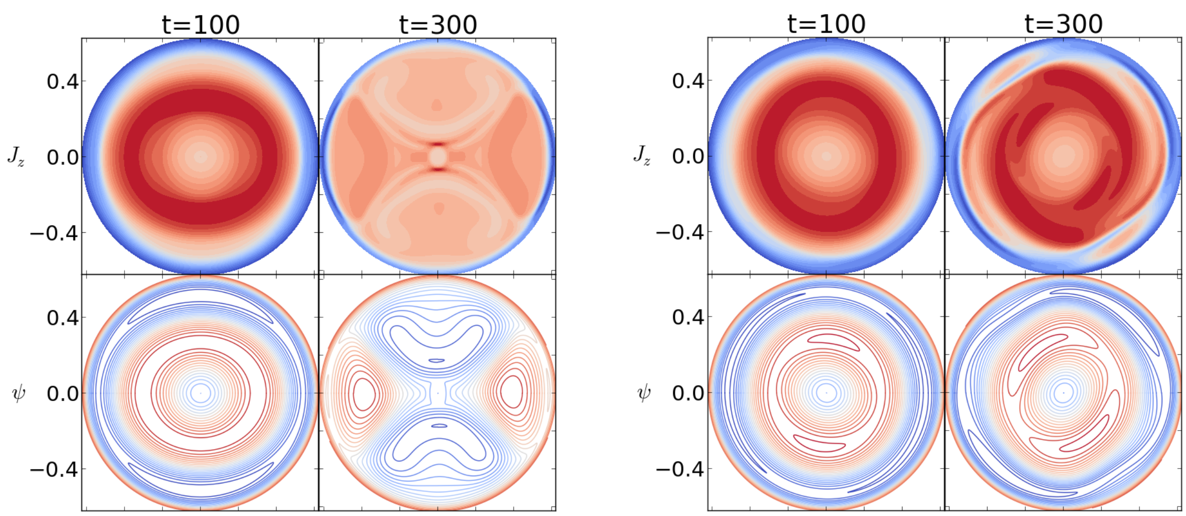
We generate our helically symmetric, cylindrical simulation equilibria using a safety factor profile of drawn from [2] with two $q = 2$ rational surfaces spaced a distance $D \approx 0.26$ apart. Using a tunable profile, we can adjust the gradient maximum location, width, and height to elucidate their respective roles. instability in this equilibrium. By locating the center of a steep density gradient at this surface we are therefore able to maximize the stabilizing effects of the diamagnetic drift local to the tearing layer while still providing the global differential rotation necessary to decouple the two surfaces of the DTM.

We were able to show a significant decrease of the linear growth rate (γ) of a $m = 2$, $n = 1$ double-tearing mode by increasing the electron diamagnetic drift frequency at the outer rational surface ($\omega_*(r_{s2})$). The growth rate shows an inflection point at $\omega_*(r_{s2}) \approx 0.015$ which indicates the critical drift for decoupling the two rational surfaces. Above this value the growth rate is further reduced by local diamagnetic stabilization of the outer tearing layer, an effect not present with equilibrium sheared flow. At very steep density gradients, however, the mode growth again becomes dominated by the presence of an ideal, pressure driven instability which can be observed in the resistive simulation results.

Even when the two tearing layers are linearly decoupled the formation of large magnetic islands can re-lock the surfaces and allow development of the disruptive explosive DTM phase. We have identified the growth of the island at the outer $q = 2$ rational surface as the primary driver of this recoupling behavior. The stabilization behavior we have observed linearly, however, remains effective nonlinearly for sufficiently strong drifts. This $m = 2$,

$n = 1$ DTM will, in force-free equilibria without a diamagnetic drift, rapidly develop magnetic islands which disrupt the annular current ring (Fig. 1a). Applying a strong diamagnetic drift of $\omega_*(r_{s2}) = 0.05$ at the outer resonant surface, however, greatly reduces the growth these islands. In our simulations this drift is sufficient to not only decouple the two surfaces but also to prevent the outer magnetic islands from growing large enough to recouple the mode, even at late times (Fig. 1b). The annular current ring is, therefore, preserved.

Using nonlinear `MRCv3` cylindrical simulations we have demonstrated that diamagnetic drifts are an effective means of decoupling double-tearing modes and preventing the onset of nonlinear explosive growth. This mechanism may be able to mitigate the occurrence of off-axis sawtooth disruptions in reverse magnetic shear devices. Our investigations have, however, also shown that differential rotation is necessary to decouple the DTM surfaces. As a consequence, the nonlinear behavior of the instability depends strongly on the location of the pressure gradient. An important future direction for this work is to combine equilibrium diamagnetic drifts with bulk plasma flows (either externally driven or due to intrinsic rotation) which would aid in decoupling the DTM surfaces. In such scenarios it may be possible to apply a significant ω_* drift to both rational surfaces, thereby further slowing the development of magnetic islands.



(a) Force-Free

(b) $\omega_*(r_{s2}) = 0.05$

Figure 1: Nonlinearly the force-free $m = 2$, $n = 1$ DTM develops large magnetic islands at both $q = 2$ rational surfaces which disrupt the annular current. A strong diamagnetic drift centered at the outer rational surface, however, decouples the tearing layers and prevents the formation of large islands, preserving the current ring even at late times.

Plasma echos in weakly collisional plasmas

In [6], we numerically investigated the discrete complete eigenmode spectrum of Landau damped modes that appears when including a Lenard-Bernstein type weak collision operator into the Vlasov system, confirming the results from *Ng. et al*'s earlier work [7]. We have since continued research into this topic, to shed light on the apparent contradicting claims from Su and Oberman, which expect the echo to damp as $\exp(-\beta\omega_p^2 t^3)$ with the third power in t, while Ng's work would suggest that there should be a regime where the echo decays like the eigenmodes themselves as $\exp(-\beta t)$, ie., with the first power in t. We have a paper in preparation that explains in detail how only the intermediate Su-Oberman regime actually produces as observable echo, satisfying their prediction even in the picture of a superposition of discrete eigenmodes.The long time regime, where one does observe the first power decay for the individual modes, does however not have enough information left to actually produce a discernible echo.

Multi-fluid moment modeling

We have applied a new class of plasma fluid models, the so-called multi-fluid moment models to reconnection in generic simplified model systems, in particular the Harris sheet [8] and the island coalescence problem [9]. The fluid evolution equations in these models treat both ion and electron species on equal footing and are derived from the Vlasov equation without any simplifying assumptions, just by taking moments. However, the fluid equations need to be closed, and we investigated two cases: The five moment model includes a simple scalar pressure per species and an adiabatic equations of state (zero heat flux) is assumed. This model is essentially equivalent to regular extended MHD generalized Ohm's laws, incorporating Hall term, electron pressure gradient and electron inertia. The 10 moment model evolves the full pressure tensor for each species and a simplified Hammett-Perkins closure for the heat flux. Our results show that the 10 moment model gets the basic collisionless reconnection structure correct (as compared to a fully kinetic PIC simulation), where the electric field at the X point is carried by off-diagonal elements of the electron pressure tensor.

Simulating magnetic reconnection between colliding magnetized laser-produced plasmas

We have continued our collaboration with the Princeton group around Will Fox on simulation support of HED experiments involving formation and reconnection of magnetic fields. Our particle-in-cell code PSC played a crucial role in providing insights from fully kinetic simulations.

Shining high-power lasers on flat targets produces expanding plasma bubbles. They self-generate a strong magnetic field of order megagauss, which forms a toroidal ribbon wrapping around the bubble by the Biermann battery process. If multiple bubbles are created at small separation, the bubbles expand into one another, squeezing the opposing magnetic fields together and driving reconnection. Despite the small physical size (mm to cm-scale), due to the high energy density, in dimensionless measures (L/d_i) these are some of the largest reconnection experiments. Our collaborative work on 2-d simulations explained the observed seemingly super-Alfvenic reconnection rates in terms of nominal plasma parameters by magnetic flux pileup increasing the local Alfven velocity, and also observed the break-up of the current sheet into multiple plasmoids in a sufficiently weakly collisional regime.

End-to-end simulations of laser-generated plasma bubble experiments

Because the 2-d simulations can by design not represent gradients in the out-of-plane direction, the Biermann-battery process that self-consistently generates the magnetic ribbons is surpressed in such simulations. The simulations were therefore run with already formed bubbles, including magnetic fields, in the initial condition and only the expansion and colliding of those bubbles, starting off reconnection was studied.
This work has now been extended to 3-d end-to-end simulations, which cover the entire process from the formation of the bubbles, through the generation of magnetic fields to their final reconnection and annihilation, with a first paper to be submitted soon. These simulations required additional computational work, including a plasma injection and heating operators that represent the ablation and heating of the targets by the laser beams.

Plasma Simulation Code

The Particle Simulation Code (PSC) was originally written by Prof. Ruhl, Ludwig-Maximilians-University Munich, Germany, but development is now lead by the PI. The PSC was primarily used in the direct simulation of laser-plasma interaction, but is now used by the PI and other scientists at UNH and PPPL to study magnetic reconnection in laser plasma bubbles, in a (solar and magnetospheric) space plasma context and for fundamental studies of kinetic magnetic reconnection with the goal of incorporating essential kinetic physics into plasma fluid models.
We in particular optimized the load balancing algorithm in PSC, a unique feature that can provide dramatic performance improvements over other existing PIC codes. We have written a methods paper that has been published in the Journal of Computational Physics and performed detailed comparisons to the VPIC code.
Fig. 2 shows three approaches to domain decomposition in particle in cell codes: (a) uniform decomposition (the grid shown here and in the following is the mapping from the domain to cores, ie., every rectangle corresponds to the subdomain handled by one particular MPI process). Some processes handle up to 10× more than particles than others, leading to a large imbalance. (b) "rectilinear" decomposition. Boundaries between processes can be adjusted, which reduces the imbalance significantly, but actual balance cannot typically by achieved. (c) "Patch-based" load balancing as implemented in PSC, where each MPI process handles multiple patches, which can be assigned due processes dynamically in order to get close to ideal load balance.
The performance results are summarized in the following table. The new method show impressive gains over even a dynamically rectilinear load-balanced simulation, and gains of a factor of 10× or more compared to conventional uniform domain decomposition.

balancing method	initial	first 30,000 steps	all 60,000 steps
uniform	9.9×	n/a	n/a
static rectilinear	1.66×	3.64×	n/a
dynamic rectilinear	1.66×	1.94×	1.87×
dynamic patch-based	1×	1×	1×

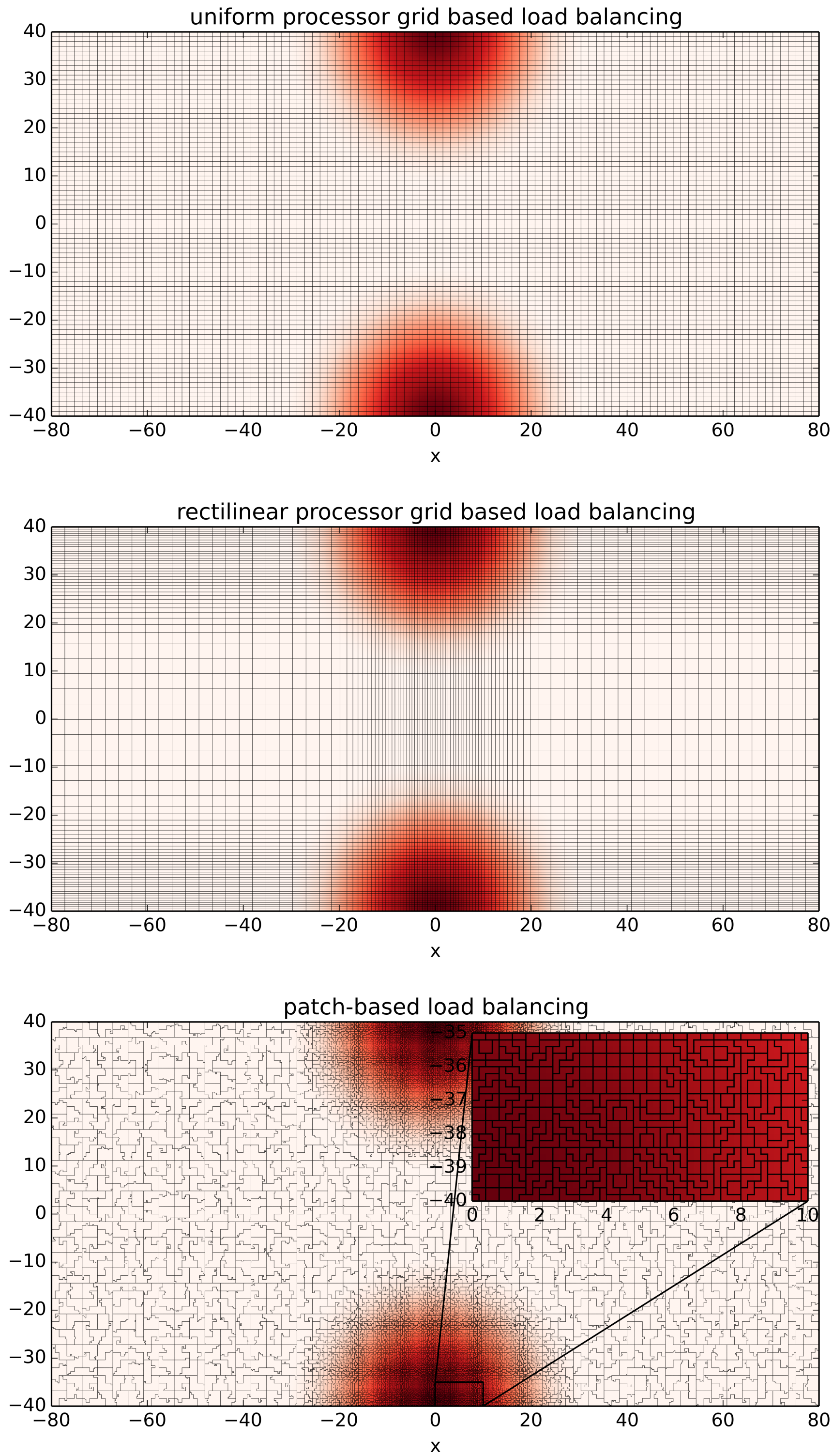


Figure 2: Domain decomposition, top to bottom: (a) uniform (b) rectilinear (c) patch-based.

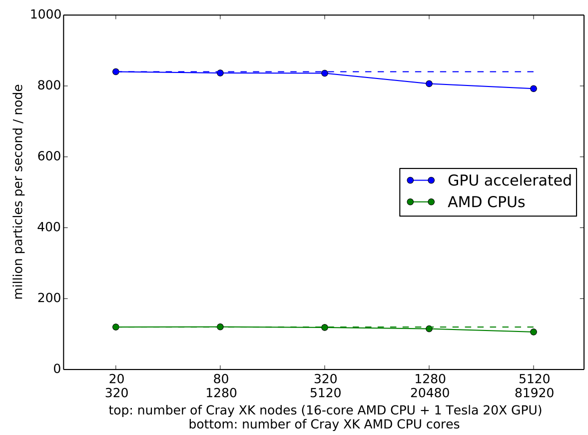


Figure 3: PSC scalability on Titan using CPUs only (green) and GPUs (blue).

In addition, Fig. 3 shows the excellent parallel scalability of the PSC code and the substantial performance gains of up to 6× from using the GPUs on Oakridge's Titan machine.

Numerical methods for MHD / extended MHD

Numerous computational advances on fluid models, specifically MHD, extended MHD and multi-moment fluid models have been implemented in the course of this project and are available as open source in the libMRC library, which is used as the basis for our psc and mrcv3 codes, as well as the global magnetosphere code openggcm.
These include constrained transport MHD / extended MHD schemes including CWENO and VLCT schemes, as well as fully cell-centered schemes with different different cleaning options. A new Schur-complement based preconditioning method has been implemented in mrcv3 in addition to the existing distributed direct solver machinery to support implicit time integration.
The CWENO and Van-Leer Constrained Transport (VLCT) schemes have been implemented and benchmarked with success. In addition, we have also interfaced the gkeyll code to libmrc, which provides new physics models based on a multi-fluid moment description, though more work remains done in developing / validating pressure tensure closures.
We have also developed 3-d block-structured AMR capabilities on staggered grids (so far except actual dynamic regridding) and implemented those into libmrc. Fig. 4 shows an example of a magnetized Kelvin-Helmholtz instability testing this feature.

Personnel

The project has supported two post-docs, Liwei Lin and then Liang Wang, as well as fully the PhD work of graduate student Steve Abbott and to a small extent the work of PhD students Narges Ahmadi and Kris Maynard. Steve Abbott and Narges Ahmadi have both graduated and gone on to good positions. Steve Abbott took a postdoctoral position at ORNL working on adapting plasma codes to a new generation of computing hardware. He has now moved to a position at Nvidia, still working at ORNL as point of contact for their upcoming Summit machine. Narges Ahmadi took a postdoctoral position at CU Boulder with Bob Ergun in magnetospheric physics.

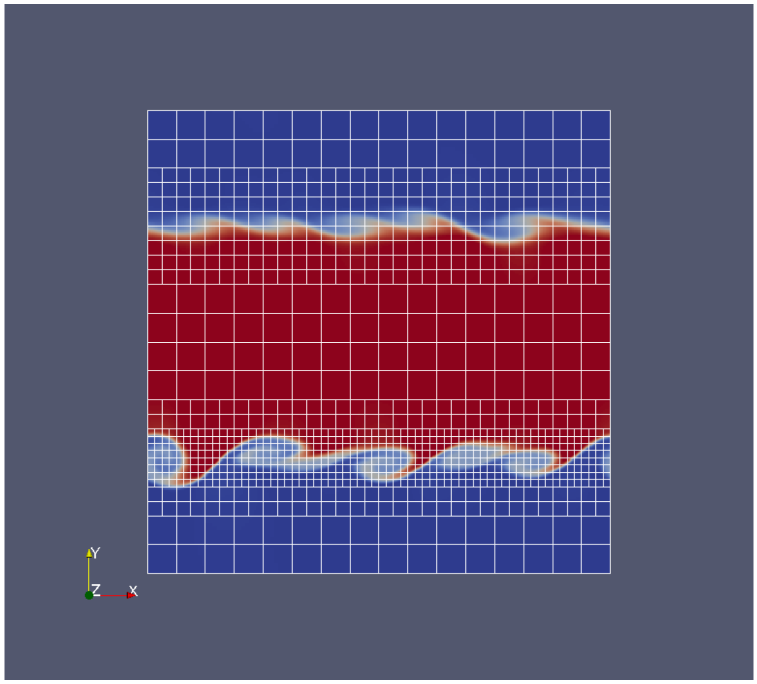


Figure 4: Kelvin-Helmholtz test problem for adaptive mesh refinement

Publications, Presentations, Products

Publications related to this grant

- L. Wang, K. Germaschewski, A. Hakim, C.F. Dong, J. Raeder, A. Bhattacharjee, *Electron Physics in 3D Two-Fluid Ten-Moment Modeling of Ganymedes Magnetosphere*, under review, J. Geophys. Res.

- J. Matteucci, W. Fox, A. Bhattacharjee, D. Schaeffer, C. Moissard, K. Germaschewski, G. Fiksel, S. Hu, *Interplay of Biermann-battery and magnetic reconnection in 3-D colliding laser plasmas*, in preparation for Phys. Plasmas (arXiv:1710.08556)

- S. Abbott and K Germaschewski, *Effect of electron diamagnetic drifts on cylindrical double-tearing modes*, in preparation for Phys. Plasmas (arXiv:1508.01959)

- DB Schaeffer, Will Fox, Dan Haberberger, Gennady Fiksel, Amitava Bhattacharjee, DH Barnak, SX Hu, and Kai Germaschewski, *Generation and Evolution of High-Mach-Number Laser-Driven Magnetized Collisionless Shocks in the Laboratory*, Physical Review Letters 119 (2), 025001 (2017)

- K. Germaschewski, W. Fox, N. Ahmadi, L. Wang, S. Abbott, H. Ruhl, and A. Bhattacharjee, *The Plasma Simulation Code: A modern particle-in-cell code with patch-based load-balancing*, J. Comput. Phys. 318, 305-326 (2016)

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  The island coalescence problem: Scaling of reconnection in extended fluid models including higher-order moments Phys. Plasmas 22, 112104 (2015)

- N. Bessho, L.-J. Chen, K. Germaschewski, and A. Bhattacharjee,
  Electron acceleration by parallel and perpendicular electric fields during magnetic reconnection without guide field, J. Geophys. Res., 2015JA021548 (2015)

- L. Wang, A.H. Hakim, A. Bhattacharjee, and K. Germaschewski,
  Comparison of multi-fluid moment models with particle-in-cell simulations of collisionless magnetic reconnection, Phys. Plasmas 22, 012108 (2015)

- S. D. Baalrud, T. Lafleur, W. Fox, K. Germaschewski
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  Plasma Sources Science and Technology 24 (1), 015034 (2015)

- G. Fiksel, W. Fox, A. Bhattacharjee, D.H. Barnak, P.Y. Chang, K. Germaschewski, et al.
  Magnetic Reconnection between Colliding Magnetized Laser-Produced Plasma Plumes
  Physical Review Letters 113 (10), 105003 (2014)

- W. Fox, A. Bhattacharjee, and K. Germaschewski, *Magnetic reconnection in high-energy-density laser-produced plasmas*, Phys. Plasmas 19, 056309 (2012)

- C. Black, K. Germaschewski, A. Bhattacharjee, and C. S. Ng, *Discrete kinetic eigenmode spectra of electron plasma oscillations in weakly collisional plasma: A numerical study*, Physics of Plasmas 20, 012125 (2013)

- W. Fox, G. Fiksel, A. Bhattacharjee, P.-Y. Chang, K. Germaschewski, S. X. Hu, and P. M. Nilson, *Observation of Weibel instability in counter-streaming laser-driven plasmas*, Phys. Rev. Lett. 111, 225002 (2013)

Presentations related to this grant

- *K. Germaschewski, L. Wang, J. Raeder, K. Maynard, A. Bhattacharjee*
  Next-generation OpenGGCM
  LWS/SC Technical Interchange Meeting, Mountain View, CA (May 2017)

- *Kai Germaschewski, Liang Wang, Jimmy Raeder, Kris Maynard* Next Generation OpenGGCM LWS team meeting, Princeton, NJ (Apr 2017)

- *Derek Schaeffer, Will Fox, Dan Haberberger, Gennady Fiksel, Amitava Bhattacharjee, Daniel Barnak, Suxing Hu, Kai Germaschewski*
  Laboratory Observation of High-Mach Number, Laser-Driven Magnetized Collisionless Shocks
  AAS Meeting 2017

- *L Wang, K Germaschewski, A Hakim, A Bhattacharjee, C Dong*
  Three-Dimensional Multi-fluid Moment Simulation of Ganymede
  AGU Fall Meeting, San Francisco, CA (Dec 2016)

- *W Fox, D Schaeffer, D Haberberger, G Fiksel, A Bhattacharjee, D Barnak, S Hu, K Germaschewski*
  Laboratory Observation of Laser-Driven, Supercritical Collisionless Shocks
  AGU Fall Meeting, San Francisco, CA (Dec 2016)

- *N Ahmadi, MR Argall, KW Paulson, R Ergun, FD Wilder, K Germaschewski, YV Khotyaintsev, RB Torbert, CT Russell, RJ Strangeway, W Magnes, O Le Contel, BL Giles* Observation and Simulation of Chorus Waves Generation at the Gradients of Magnetic Holes
  AGU Fall Meeting, San Francisco, CA (Dec 2016)

- *Chuanfei Dong, Liang Wang, Amitava Bhattacharjee, Ammar Hakim, Yi-Min Huang, Kai Germaschewski* Magnetic reconnection in multispecies plasmas investigated by a kinetic fluid code APS/DPP Meeting (Nov 2016)

- *L. Wang, K. Germaschewski, A. Hakim, A. Bhattacharjee, C. Dong*
  An extensible multi-fluid moment framework with application to space environments
  SHINE meeting, Santa Fe, NM (Jul 2016)

- *K. Germaschewski, L. Wang, J. Raeder, K. Maynard, A. Hakim, A. Bhattacharjee*
  Next-generation OpenGGCM
  GEM meeting, Santa Fe, NM (Jun 2016)

- *K. Maynard, K. Germaschewski, J. Raeder*
  Flux Transfer Events OpenGGCM
  GEM meeting, Santa Fe, NM (Jun 2016)

- *N. Ahmadi, K. Germaschewski, and J. Raeder*
  Nonlinear Evolution of Mirror Instability into Magnetic Holes
  GEM meeting, Santa Fe, NM (Jun 2016)

- *K. Germaschewski, L. Wang, J. Raeder, K. Maynard, A. Hakim, A. Bhattacharjee*
  Next-generation OpenGGCM
  LWS/SC Technical Interchange Meeting, Mountain View, CA (May 2016)

- *K. Germaschewski, L. Wang, J. Raeder, K. Maynard*
  Status of the next-generation OpenGGCM
  LWS team meeting, Princeton, NJ (Apr 2016)

- *K. Germaschewski*
  Insights into magnetic reconnection through high-performance simulations
  Physics Colloquium, Dartmouth College, Hanover, NH (Feb 2016)

  K. Germaschewski, L. Wang, K. Maynard, J. Raeder, and A. Bhattacharjee
  (invited) Integration of Extended MHD and Kinetic Effects in Global Magnetosphere

Models
AGU Fall Meeting, San Francisco, CA (Dec 2015)

- *N. Ahmadi, K. Germaschewski, and J. Raeder*
  Effects of Electron Temperature Anisotropy on Mirror Instability Evolution in the Magnetosheath
  AGU Fall Meeting, San Francisco, CA (Dec 2015)

- *K. Germaschewski, L. Wang, K. Maynard, and J. Raeder*
  Integrating extended MHD and kinetic physics into the next-generation OpenGGCM
  AGU Fall Meeting, San Francisco, CA (Dec 2015)

- *L. Wang, K. Germaschewski, A. Hakim, J. Raeder, and A. Bhattacharjee*
  Multi-Fluid Moment Simulations of Ganymede using the Next-Generation OpenGGCM
  AGU Fall Meeting, San Francisco, CA (Dec 2015)

- *C. Black, S. Antiochos, K. Germaschewski, J. Karpen, C. R. DeVore, and N. Bessho*
  Shear-Driven Reconnection in Kinetic Models
  AGU Fall Meeting, San Francisco, CA (Dec 2015)

- *V. Roytershteyn, H. Karimabadi, Y. Omelchenko, and K. Germaschewski*
  Turbulence dissipation challenge: particle-in-cell simulations
  AGU Fall Meeting, San Francisco, CA (Dec 2015)

- *S. Abbott, K. Germaschewski*
  Nonlinear Diamagnetic Stabilization Effects on m = 2, n = 1 Cylindrical Double-Tearing Modes in Hall MHD Simulations
  Sherwood Fusion Theory Workshop, New York, NY (2015)

- *K. Germaschewski, W. Fox, S. Abbott*
  Exploiting the Power of Heterogeneous Computing for Kinetic Simulations of Plasmas
  Sherwood Fusion Theory Workshop, New York, NY (2015)

- *K. Maynard, K. Germaschewski, L. Lin, J. Raeder*
  Hall MHD in the Magnetopause with OpenGGCM
  AGU fall meeting, San Francisco, CA (2014)

- *N. Ahmadi, K. Germaschewski, J. Raeder*
  Nonlinear Evolution of the Mirror Instability in the Magnetosheath Using PIC Simulations
  AGU fall meeting, San Francisco, CA (2014)

- *L. Wang, A. Hakim, A. Bhattacharjee, K. Germaschewski*
  Integrating kinetic effects in fluid models for magnetic reconnection
  AGU fall meeting, San Francisco, CA (2014)

- *W. Fox, A. Bhattacharjee, W. Deng, C. Moissard, K. Germaschewski, G. Fiksel, D. Barnak, P.-Y. Chang, S. Hu, P. Nilson*

Laboratory Magnetic Reconnection Experiments with Colliding, Magnetized Laser-Produced Plasma Plumes
AGU fall meeting, San Francisco, CA (2014)

- *G Fiksel, DH Barnak, PY Chang, D Haberberger, SX Hu, S Ivancic, et al.*
  Strongly Driven Magnetic Reconnection in a Magnetized High-Energy-Density Plasma
  Bulletin of the American Physical Society 59 (2014)

- *S Abbott, K Germaschewski*
  Nonlinear Diamagnetic Stabilization of Double Tearing Modes in Cylindrical MHD Simulations
  Bulletin of the American Physical Society 59 (2014)

- *K Germaschewski, N Ahmadi, S Abbott, L Lin, L Wang, A Bhattacharjee, et al.*
  High-Performance Kinetic Plasma Simulations with GPUs and load balancing
  Bulletin of the American Physical Society 59 (2014)

- *W Fox, G Fiksel, A Bhattacharjee, PY Change, K Germaschewski, S Hu, et al.*
  Astrophysical Weibel instability in counterstreaming laser-produced plasmas
  American Astronomical Society Meeting Abstracts 224 (2014)

- Feb 2014: Two invited presentations at SIAM conference on Parallel Processing for Scientific Computing, Portland, OR

- Apr 2013, "Simulations of Double Tearing Modes in Cartesian and Cylindrical Geometries using the MRC Code", poster at Sherwood conference, Santa Fe, NM

- Apr 2013, "Exploiting the Power of Heterogeneous Computing for Particle-In-Cell Simulations of Plasmas", poster at Sherwood conference, Santa Fe, NM

- Mar 2013, "Present and future computational requirements for general plasma physics", presentation at DOE/FES NERSC workshop, Rockville, MD

- Mar 2013, "Benchmark Analysis of Plasma Simulations on modern compute architectures", presentation at SIAM/SEAS meeting, Knoxville, TN

- Jan 2013, "Exploiting the power of heterogeneous computing for kinetic simulations of plasmas", seminar talk at Ruhr-University Bochum, Germany

- Dec 2012, "Exploiting the power of heterogeneous computing for kinetic simulations of plasmas", Frontiers in Computational Science, Boulder, CO

- Nov 2012, "Simulating magnetic reconnection in high-energy-density plasmas with the PSC particle-in-cell framework", APS/DPP meeting, Providence, RI

- Nov 2012, "Nonlinear evolution of m=1 and higher m tearing modes in tokamaks in cylindrical and slab models", APS/DPP meeting, Providence, RI

- Jul 2012, "Dynamic Load-Balancing and GPU Computing with the Particle-In-Cell code PSC", seminar talk at Ludwig-Maximilians-University, Munich, Germany

- Jan 2012, "Computational Advancements in Fluid and Kinetic Plasma Simulations", presentation at CICART advisory meeting, UNH
- Jan 2012, "Computational Advancements in Fluid and Kinetic Plasma Simulations", Presentation at CICART advisory meeting, UNH
- Jan 2012, "Computational Aspects of OpenGGCM", Invited Talk at CCMC workshop, Key Largo, FL
- Dec 2011, "Dynamic Load-Balancing and GPU Computing with the Particle-In-Cell code PSC", AGU meeting, San Francisco, CA
- Nov 2011, "Dynamic Load-Balancing and GPU Computing with the Particle-In-Cell code PSC", APS/DPP meeting, Salt Lake City, UT
- Nov 2011, "Diamagnetic Effects on Double Tearing Modes", APS/DPP meeting, Salt Lake City, UT
- Sep 2011, "GPU Computing With the Particle-In-Cell Code PSC", ICNSP'11, Long Branch, NJ

Products related to this grant

- `http://fishercat.sr.unh.edu/trac/libmrc`. libMRC is a library developed by the PI and collaborators that forms the core of various codes, including psc,mrcv3 and openggcm. It also is the basis for our automatic code generation engine and has been made available on the web. It is used in production already and many of its features are now mature, though active development of new features is still underway.

  We have made substantial progress in providing documentation at `http://fishercat.sr.unh.edu/libmrc/`, though there still remains a lot more to be documented.

  libMRC is tested automatically whenever new changes are committed to its source repository and current status is shown at `http://fishercat.sr.unh.edu/buildbot/waterfall`.

- `http://fishercat.sr.unh.edu/mrc-v3/`. mrcv3 is a suite of computational codes focusing of magneto-hydrodynamic (MHD) simulations of plasmas. The suite implements a variety of sophisticated numerical techniques across a wide spectrum of computing platforms, from a laptop for small simulations to large super-computing clusters. mrc is one of a growing family of simulation suites using thelibMRC computational library developed at the University of New Hampshire.

  The primary focus of development is mrc-3d, a Hall-MHD finite-volume code targeting two and three dimensional simulations in Cartesian and cylindrical geometries.

- `http://github.com/psc-code`. psc is a state-of-the-art particle in cell code. Introductory documentation is available at `http://fishercat.sr.unh.edu/psc/`. psc is an explicit three-dimensional electromagnetic code, supporting 1st and 2nd order particle shapes, provides a choice of commonly used boundary conditions, has support for a collision operator, and includes GPU-accelerated kernels. PSC implements a novel patch-based dynamic load balancing method.

References

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