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Development of the Flexo XMHD Code

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Sandia National Laboratories

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Acknowledgments

Team

- Kris Beckwith
- Stephen Bond
- Brian Granzow
- Chris Jennings
- Matt Martin
- Andy Porwitzky
- Alan Stagg
- Tom Voth

Original Perseus Fortran90

- Matt Martin
- Charles Seyler
- Yang Yang
- Xuan Zhao

Funding

- "Modeling Low Density Plasma in Electrode/Target Systems for High Current Pulsed Power" (LDRD; M. Martin)

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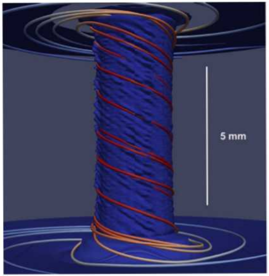
Challenges

- Simulation of imploding linear physics
- Low density electrode plasmas
- Wide range of spatial and temporal scales
- Multiple materials / EOS
- Must include the Hall term
- Must incorporate radiation physics
- Advanced computational architectures



PERSEUS simulation
C.E. Seyler, M.R. Martin, N.D. Hamlin, *Phys. Plasmas*, **25**, 062711 (2018)

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PERSEUS GOL equations

$\partial_t \rho + \nabla \cdot (\rho \mathbf{u}) = 0$	Density
$\partial_t (\rho \mathbf{u}) + \nabla \cdot (\rho \mathbf{u}\mathbf{u} + \mathbf{I} P) = \mathbf{J} \times \mathbf{B}$	Momentum
$\partial_t \mathcal{E}_n + \nabla \cdot (\mathbf{u}(\mathcal{E}_n + P)) = \mathbf{u} \cdot (\mathbf{J} \times \mathbf{B}) + \eta \|\mathbf{J}\|^2$	Total Energy
$\partial_t \mathbf{B} + \nabla \times \mathbf{E} = 0$	Magnetic Field
$\partial_t \mathbf{E} - c^2 \nabla \times \mathbf{B} = -\frac{1}{\varepsilon_0} \mathbf{J}$	Electric Field
$\partial_t \mathbf{J} + \nabla \cdot \left(\mathbf{u}\mathbf{J} + \mathbf{J}\mathbf{u} - \frac{1}{n_e e} \mathbf{J}\mathbf{J} - \frac{e}{m_e} \mathbf{I} P_e\right) = \frac{n_e e^2}{m_e} \left(\mathbf{E} + \mathbf{u} \times \mathbf{B} - \eta \mathbf{J} - \frac{1}{n_e e} \mathbf{J} \times \mathbf{B}\right)$	Current Density
$\partial_t S_e + \nabla \cdot (\mathbf{u}_e S_e) = (\gamma - 1) n_e^{1-\gamma} \eta \|\mathbf{J}\|^2$	Electron Entropy

14 or 15 moment formulation

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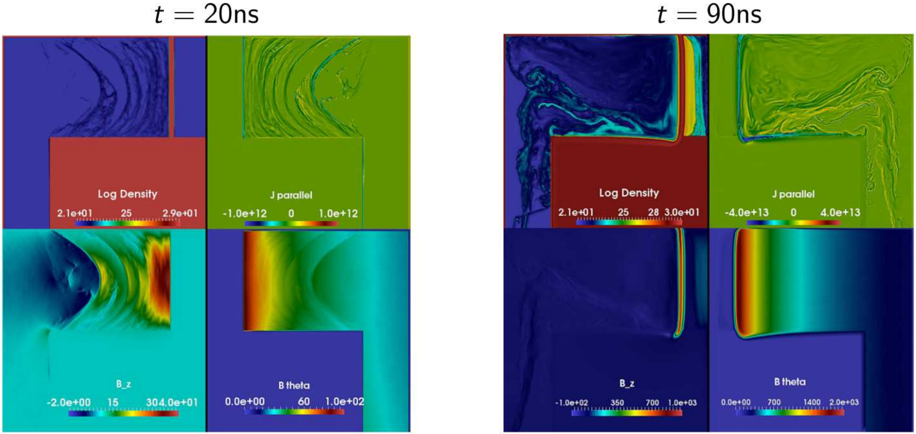
PERSEUS Results: Seyler, Martin, and Hamlin

C.E. Seyler, M.R. Martin, N.D. Hamlin, *Phys. Plasmas*, **25**, 062711 (2018)



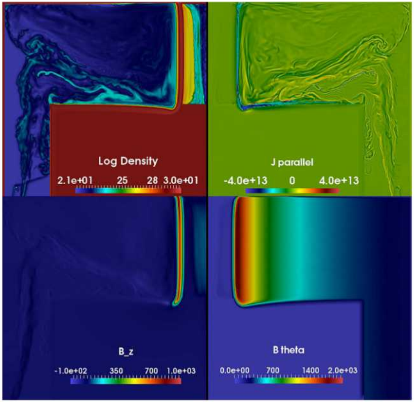
XMHD: No plasma layer initialized on feed walls

2D axial symmetric

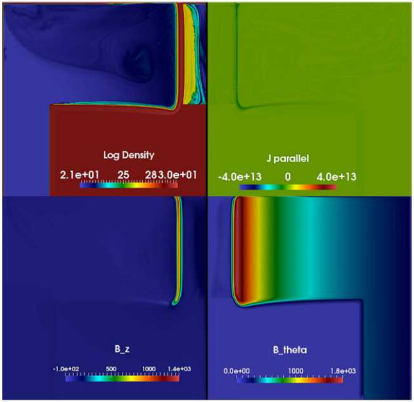
PERSEUS Results: Seyler, Martin, and Hamlin

C.E. Seyler, M.R. Martin, N.D. Hamlin, *Phys. Plasmas*, **25**, 062711 (2018)

XMHD



MHD



No plasma layer initialized on feed walls, $t = 90$ns

2D axial symmetric

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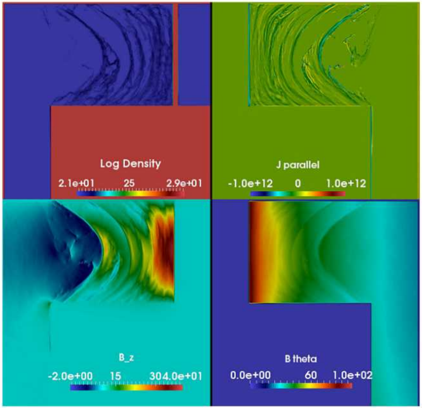
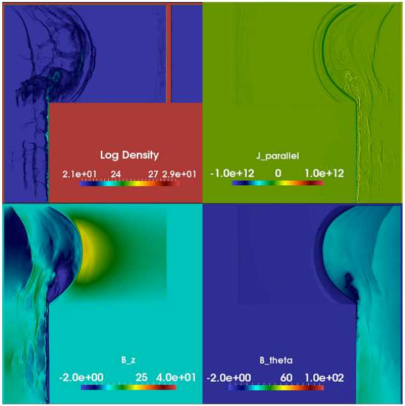
PERSEUS Results: Seyler, Martin, and Hamlin

C.E. Seyler, M.R. Martin, N.D. Hamlin, *Phys. Plasmas*, **25**, 062711 (2018)

Without initial plasma layer



With initial plasma layer

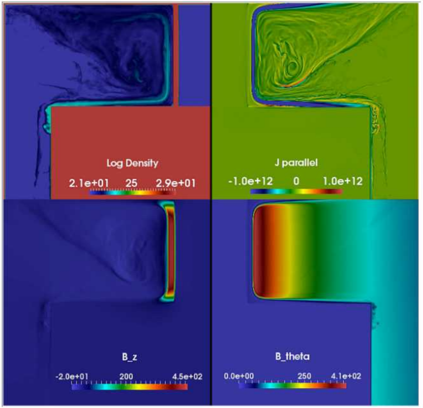


XMHD: Effect of initialization on feed walls, $t = 20$ns
2D axial symmetric

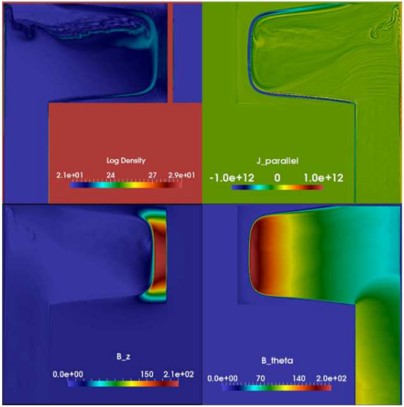
PERSEUS Results: Seyler, Martin, and Hamlin

C.E. Seyler, M.R. Martin, N.D. Hamlin, *Phys. Plasmas*, **25**, 062711 (2018)

XMHD



MHD



Plasma layer initialized on feed walls, $t = 40$ns
2D axial symmetric

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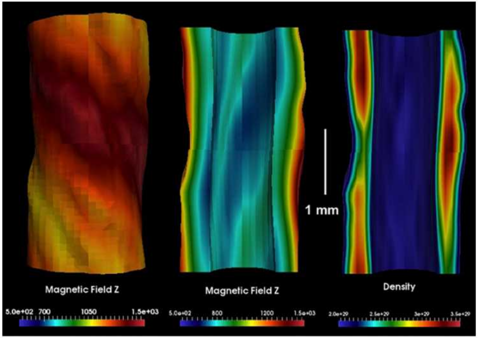
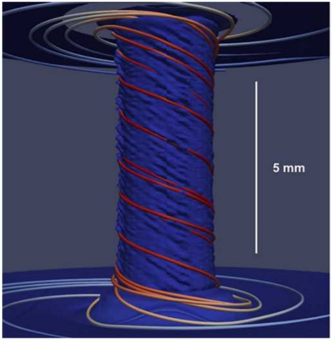
PERSEUS Results: Seyler, Martin, and Hamlin

C.E. Seyler, M.R. Martin, N.D. Hamlin, *Phys. Plasmas*, **25**, 062711 (2018)

Iso contours

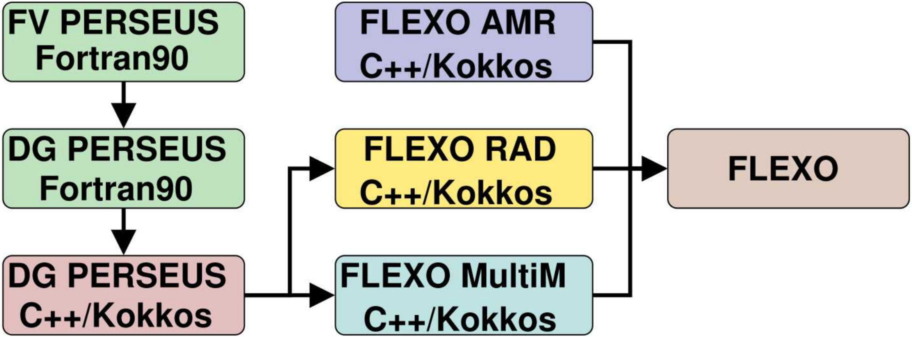


Density



Full 3D simulation

Roadmap


FV PERSEUS
Fortran90
DG PERSEUS
Fortran90
DG PERSEUS
C++/Kokkos
FLEXO AMR
C++/Kokkos
FLEXO RAD
C++/Kokkos
FLEXO MultiM
C++/Kokkos
FLEXO

Code History

- FV Perseus Fortran90 code: M. Martin and C. Seyler 2011
  - Plasma as an Extended–MHD Relaxation System using an Efficient Upwind Scheme
  - Generalized Ohm's Law 2-Fluid model (14 moment)
  - Relaxation system of equations
  - Finite Volume / Uniform Grid
  - Implicit–Explicit Monotone Upwind Scheme for Conservation Laws
  - Modified Local Lax–Friedrichs
  - Locally linearly implicit (local 3×3 linear solves)
  - Able to recover resistive-MHD limit
- DG Perseus Fortran90 code: X. Zhao, Y. Yang, and C. Seyler 2014
  - Generalized Ohm's Law 2-Fluid model (15 moment)
  - Discontinuous Galerkin extension of FV Perseus
  - Modified HLLC flux
  - Locally linearly implicit (local 3×3 linear solves)
  - Positivity preserving

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Code Future

- FLEXO
  - Generalized Ohm's Law N-Fluid + Radiation transport model
  - Discontinuous Galerkin (tensor product basis)
  - Basis constrains $\nabla \cdot \mathbf{B} = 0$ on each cell (no global constraint)
  - Positivity preserving limiters and HLLC fluxes
  - Multiple materials + pointwise single temperature
  - Modular tabular EOS
  - Coupled to full radiation transfer equation (Athena)
  - Second–order Explicit–Locally-Implicit time integration
  - OctTree AMR using Omega_h
  - MPI + Kokkos GPU acceleration

FLEXO AMR: B. Granzow and T. Voth