M3D $m = 1$ Studies and Plans

Joshua Breslau
Princeton Plasma Physics Laboratory

SCIDAC CEMM Meeting
Madison, Wisconsin
July 31, 2001

Motivation

The next generation of magnetic fusion devices will be burning plasma experiments (e.g. FIRE[1]).

- Characteristics:
  - ◇ Large fraction of energetic α-particles
  - ◇ Small normalized gyroradius
  - ◇ Low collisionality
- Scientific issues:
  - ◇ Energetic particle modes (TAE, fishbone)
  - ◇ Resistive instabilities (neoclassical tearing modes)
  - ◇ Internal kink stabilization (**giant sawtooth**)

Giant sawtooth oscillations[2] may occur when trapped energetic α-particles temporarily stabilize $m = 1$ modes. Driving energy for these modes accumulates, eventually causing a large sawtooth crash with loss of energy confinement and possible disruption.

Understanding and avoiding them is essential.

---

[1] D. M. Meade, *et al.*, PPPL-3307, Princeton Plasma Physics Laboratory (1999).

[2] W. Pfeiffer, *et al.*, Nucl. Fusion **25** 655 (1985).

Recent LHCD discharges in JET have formed core regions with zero current density.[3]

A possible explanation for this observation is as follows:

[**1.**] Off-axis current drive inductively reduces on-axis current density.

[**2.**] Core current density begins to go negative, resulting in zero-poloidal-field ($q = \infty$) surfaces at finite minor radius.

[**3.**] The region within the surface is nonlinearly unstable to an $n = 0$, $m = 1$ ideal MHD mode and is displaced inward.

[**4.**] Reconnection redistributes the central flux in a sawtooth-like event, returning the central current density to zero.

This model is relevant to sawtooth studies as well as JET discharges. Because of its 2D nature, it is amenable to testing with a 2D code.

[3] N. C. Hawkes, *et al.*, submitted to Phys. Rev. Lett. (April 2001).

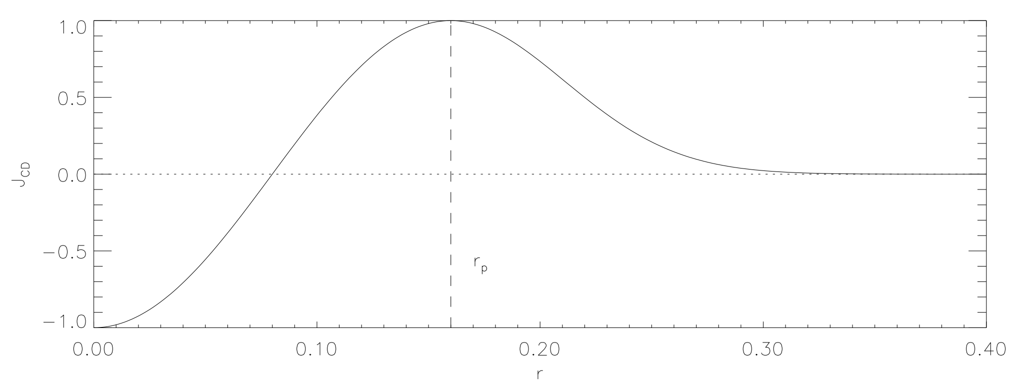
The Magnetic Reconnection Code

- 2D time-dependent code
- Original application: spheromak reconnection
- Resistive MHD and two-fluid versions exist
- Cylindrical or Cartesian geometry
- Conducting wall boundary condition
- Rectangular mesh
- ADI method allows time steps $\sim 100\times$ Courant condition.
- Code is parallel and scalable to ~ 30 processors.

Simulation Scenario

- All runs are conducted in tokamak geometry.
  - ◇ $R_{maj} = 2.5; \quad a = 0.4$
  - ◇ $B_T/B_p \sim 15$
- Initial condition: use 1D straight-cylinder equilibrium with
  - ◇ $\vec{\nabla} p = 0 \quad \rightarrow \quad \vec{J} \times \vec{B} = 0$
  - ◇ $J_\phi = J_{CD}(r) = \begin{cases} -\cos\left(\frac{\pi r}{r_p}\right), & r \leq r_p \\ \exp\left[-\frac{\pi^2}{2}\left(\frac{r}{r_p} - 1\right)^2\right], & r > r_p \end{cases}$

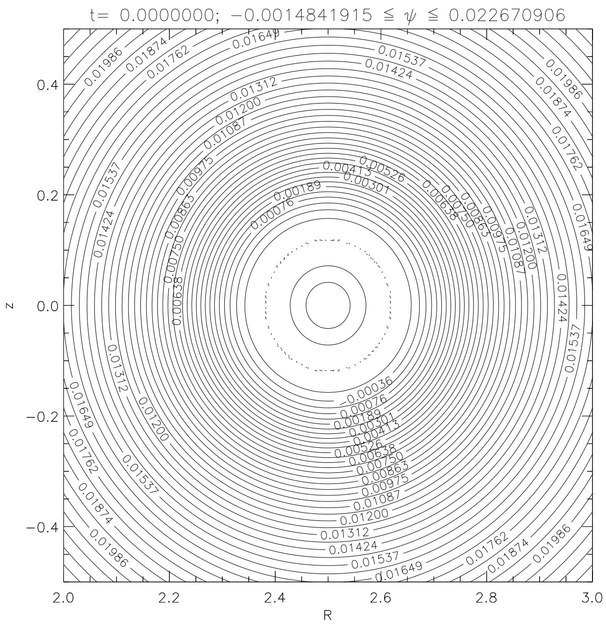
  as a small initial perturbation to a toroidal equilibrium. This gives a hollow current profile:



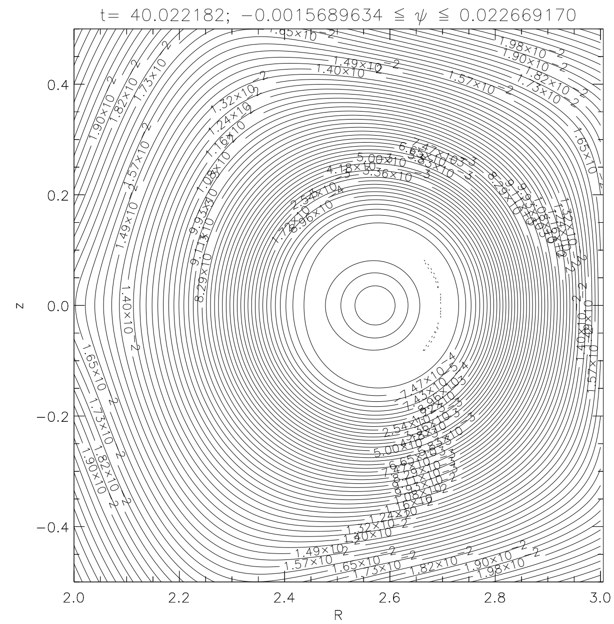
- Evolve with current drive $J_{CD}(r)$ in Ohm's law.

Early Low-β Results

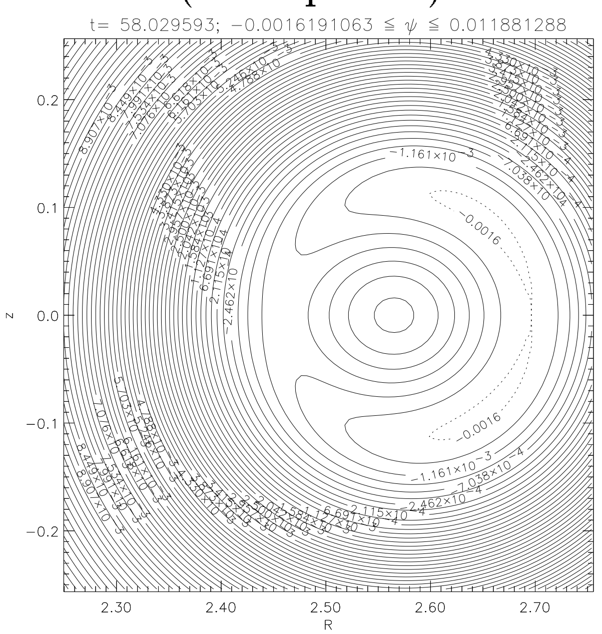
Poloidal flux contours are initially symmetric.



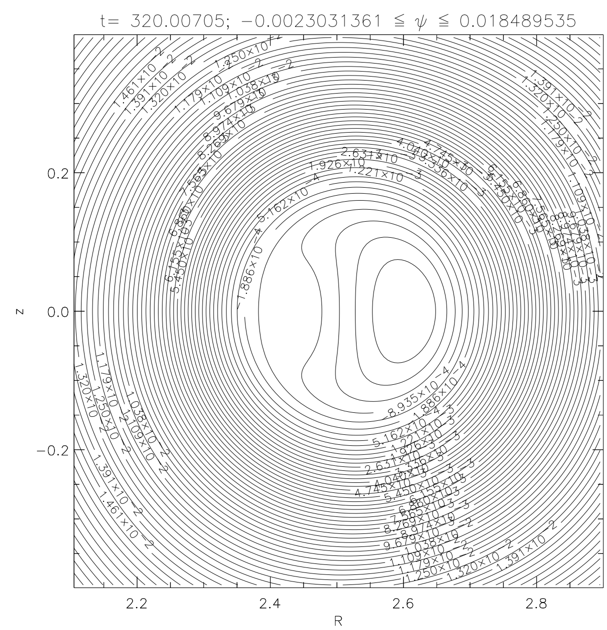
Plasma shifts outward more than core...



...resulting in reconnection. (closeup view)



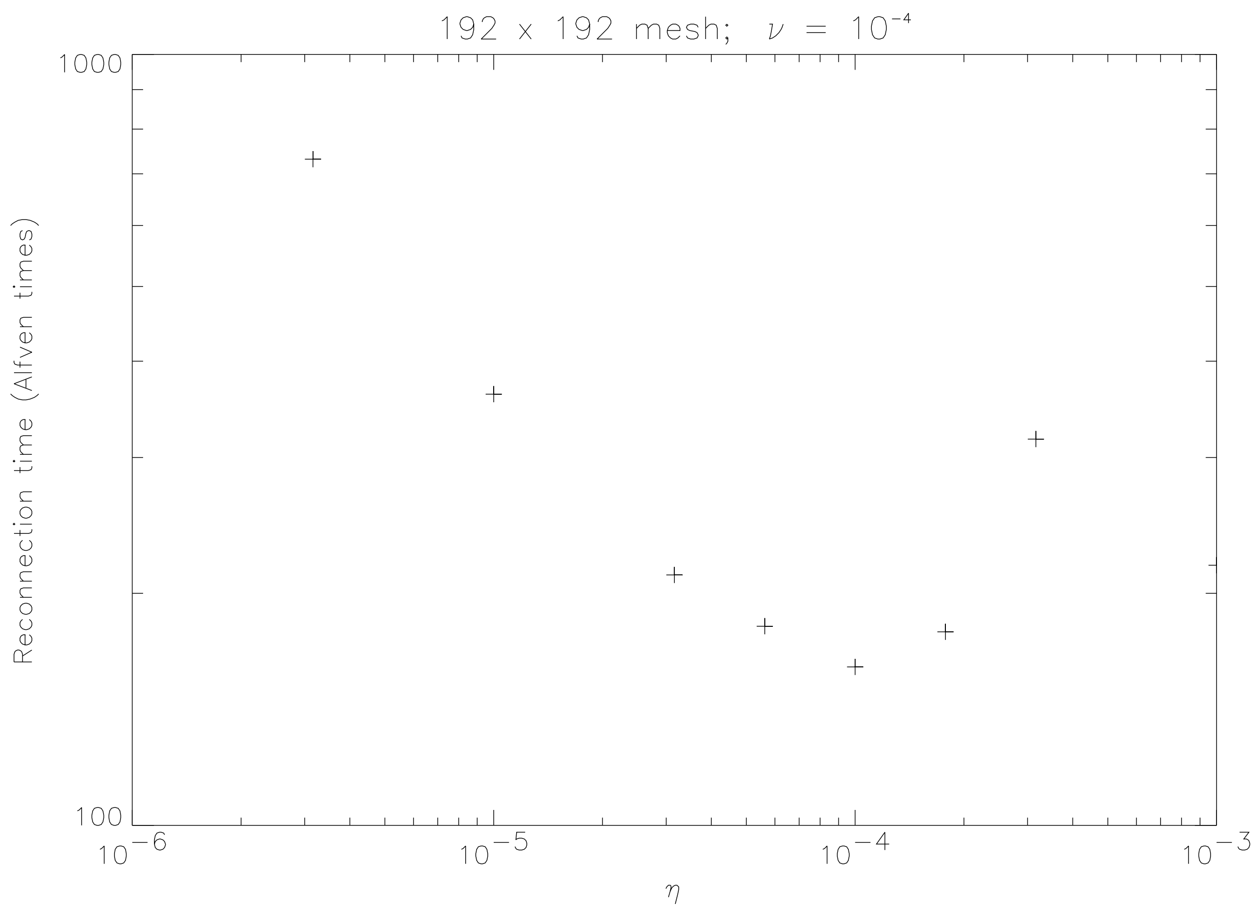
Reconnected island becomes new axis.



Resistive MHD Scaling

Preliminary study:

- Constant pressure
- Viscosity $\nu = 10^{-4}$



For $\eta < \nu$, the rate has a strong power law dependence on η.

The asymptotic limit is $\boxed{t_{rec} \propto \eta^{-1/2}}$.

Future Plans

- Magnetic reconnection code
  - ◇ Add pressure; investigate β-dependence
  - ◇ Investigate two-fluid behavior
- M3D
  - ◇ Check for consistency with MRC results
  - ◇ Move to 3D
  - ◇ Investigate $m = 1$ instability quantitatively
    - ∗ Stability threshold
    - ∗ Growth rate
    - ∗ Sawtooth period
  - ◇ Compare physics models