NIMROD VDE Modeling

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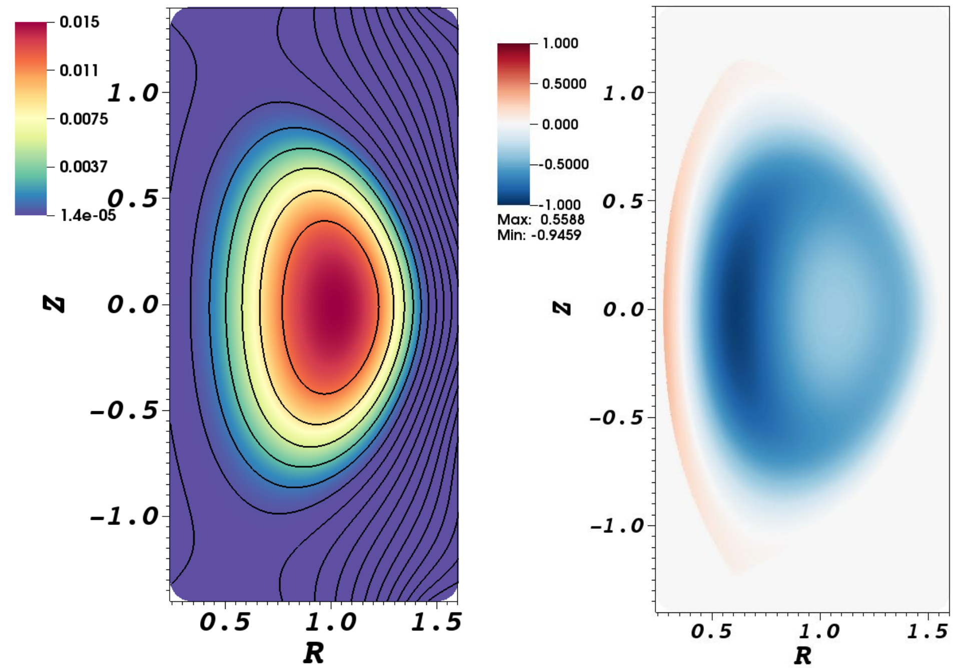
NIMROD
Non-Ideal MHD with Rotation
Open Discussion Project

Center for Tokamak Transient Simulation

NSTX VDE Benchmark Update

- NSTX VDE benchmark involves M3D-C1, NIMROD, JOREK, and possibly the LANL/Sandia SciDAC group.
- All computations so far are axisymmetric.
- Computations use modified Spitzer resistivity profiles.

$$\eta = \eta_0 \left(T - T_{off}\right)^{-3/2}$$



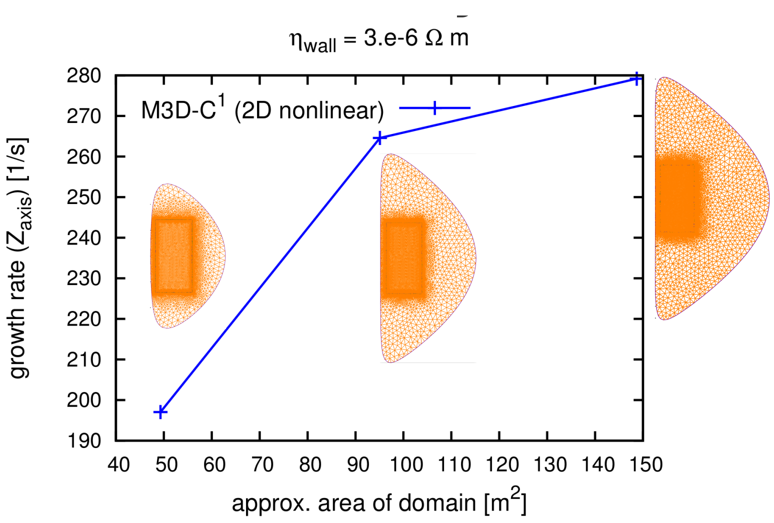
Equilibrium *P* and *Ψ* on left; J_ϕ/R on right. Note edge current layer.

- 3 sets of computations:

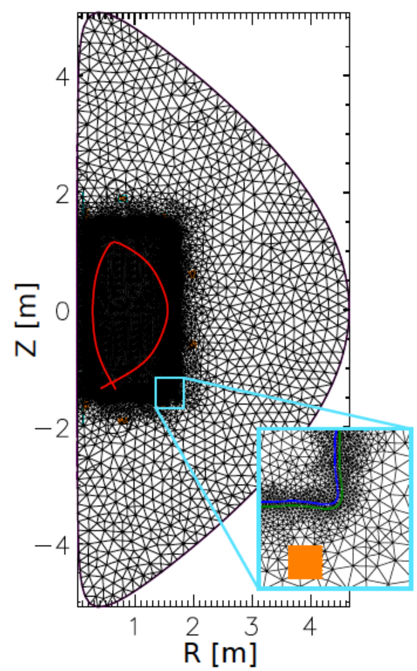
1. Linear, M3D-C1/NIMROD with $T_{off} = 0 \quad \kappa_{\|} = \kappa_{\perp}$
2. Linear phase of nonlin. M3D-C1/JOREK with $T_{off} = 13.65 \text{ eV} \quad \kappa_{\|} = 10^7 \kappa_{\perp}$
3. Nonlinear M3D-C1/JOREK/NIMROD with $T_{off} = 0 \quad \kappa_{\|} = 10^7 \kappa_{\perp}$ or $10^5 \kappa_{\perp}$

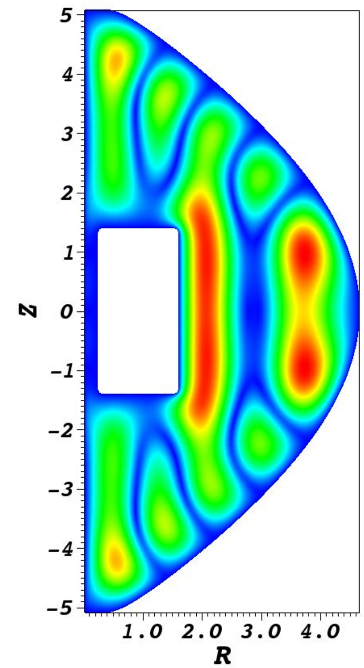
We configured NIMROD to help match the M3D-C1 runs.

- Viscosity and thermal conductivities are independent of $n(\mathbf{x})$.
- Added T_{off} , though not used in recent computations.
- Created an external vacuum where the outer geometry nearly matches that used by M3D-C1.



Krebs showed this dependence on vacuum region size last year.

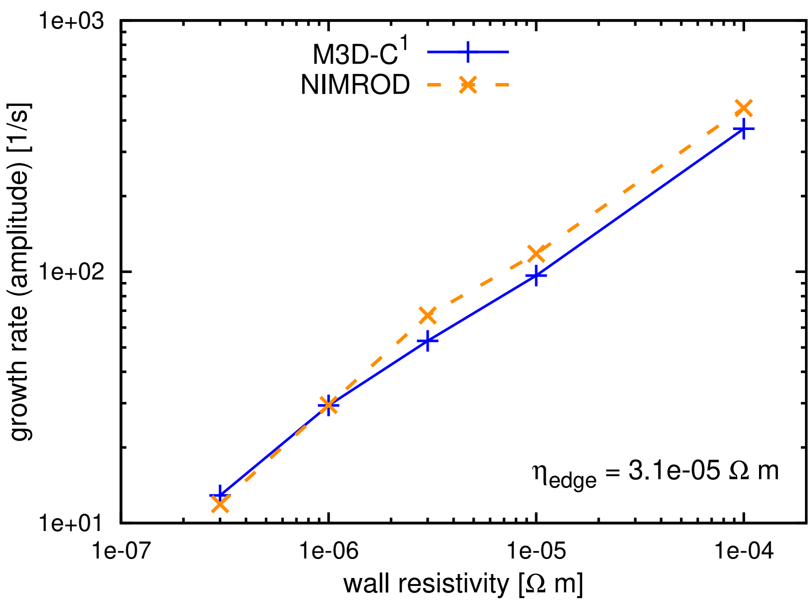




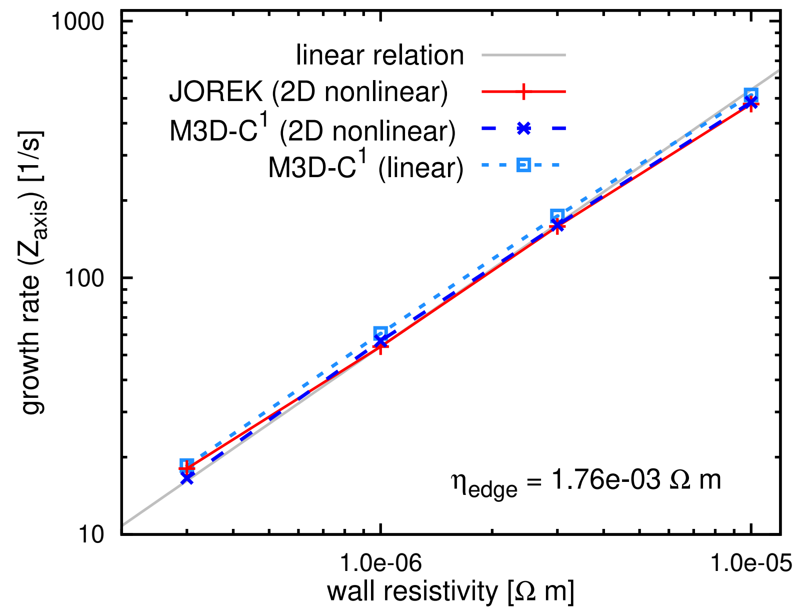
New NIMROD outer region (right − test waves plotted) is nearly the same as C1's (left).

The most recent linear comparisons are close, not perfect.

- We have been running the NIMROD computations with normalized parameters that have been checked and rechecked.



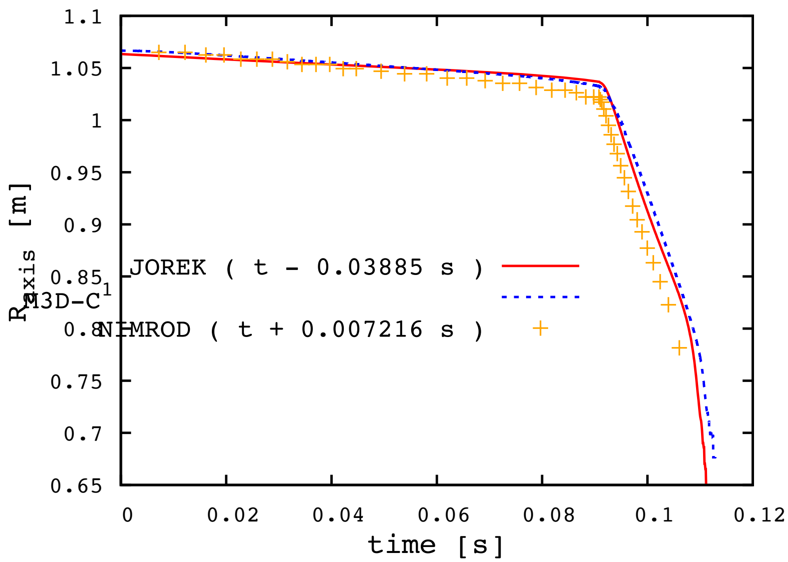
Latest comparison of true linear computations is from Krebs, *et al.* manuscript.



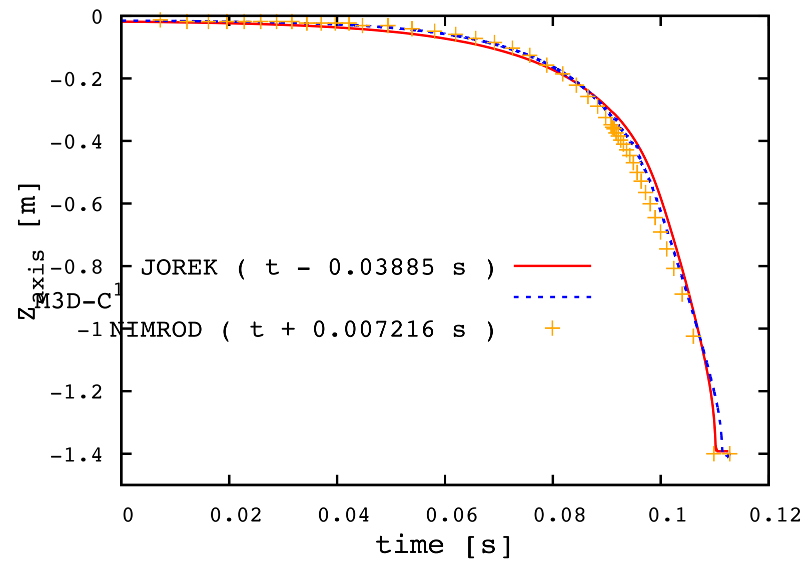
Comparison of linear phase of nonlinear computations is also from Krebs, *et al*.

First nonlinear NIMROD result is now part of the nonlinear comparison.

- Motion of magnetic axis in all three computations agrees reasonably well.
- Timings are adjusted according to contact of last closed flux surface.
    - Perpendicular thermal conductivity and particle diffusivity are increase at this time.



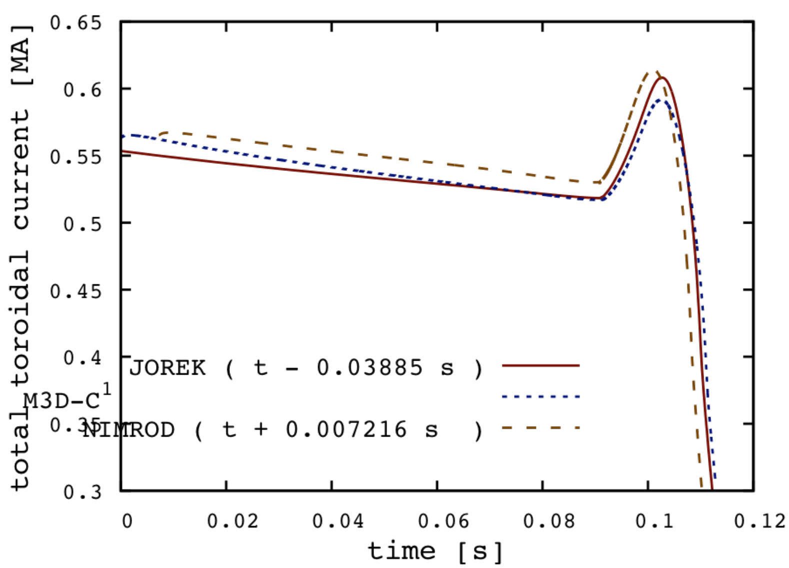
Evolution of radial position of magnetic axis.

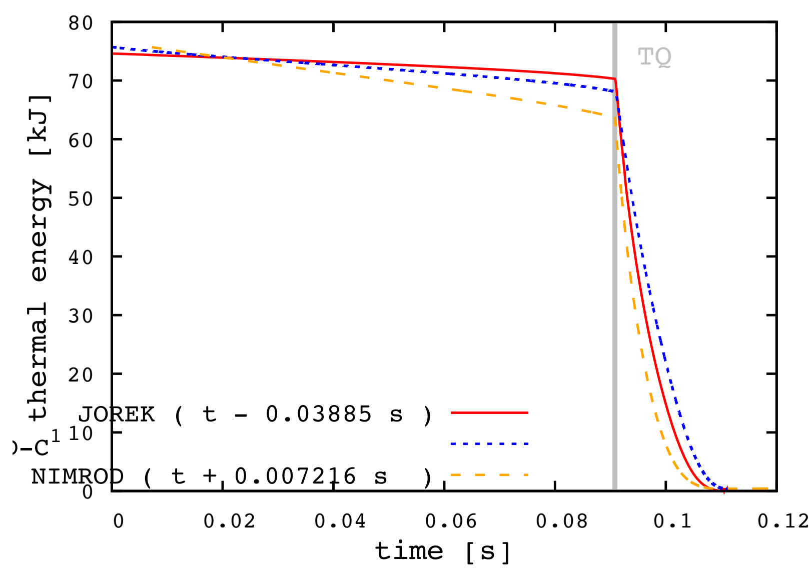


Evolution of axial position of magnetic axis.

Evolution of current and internal energy show a larger discrepancy.

- NIMROD computations were run with $\kappa_{\|} = 10^5 \kappa_{\perp}$ instead of $\kappa_{\|} = 10^7 \kappa_{\perp}$.





Plasma current evolution appears similar, although NIMROD's grows initially, likely due to loss of reversed edge current.

NIMROD computation also loses more thermal energy, even before contact of closed flux, when conduction is increased.

Update on VDE Edge/BC Modeling

- VDE evolution is influenced by open-field current.
- Predictive computation requires detailed modeling of open-field plasma conditions and boundary conditions.
- Kyle is developing simulations with:
  - Magnetized-sheath boundary conditions
  - Braginskii closures
  - More information in P2.046

Boundary modeling is based on magnetic presheath entrance conditions.

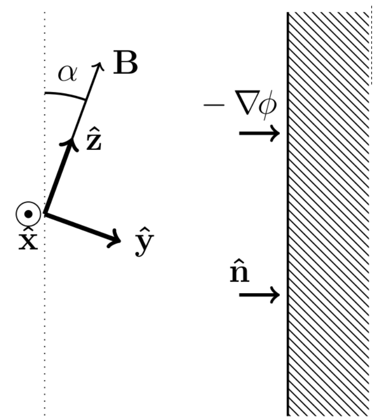
- Modeling is an adaptation of Loizu and Ricci, PoP **19**, 122307.
- Present implementation is lowest order in ρ_s/L.

$$\boxed{\hat{\mathbf{n}} \cdot \mathbf{V}_{\rm wall} = c_s \hat{\mathbf{n}} \cdot \hat{\mathbf{b}}_{\rm wall}}, \qquad \hat{\mathbf{n}} \cdot \nabla T_e = 0$$

$$\frac{T_e}{nq}\hat{\mathbf{n}} \cdot \nabla n = \hat{\mathbf{n}} \cdot \nabla\phi = -\frac{m_i c_s}{q}\hat{\mathbf{n}} \cdot \nabla(\mathbf{V} \cdot \hat{\mathbf{b}}) \sim 0$$

$$\hat{\mathbf{n}} \cdot \mathbf{J} = qnc_s \sin\alpha(1 - \exp[\Lambda - \eta])$$

- Here $\Lambda = \ln(\frac{m_i}{2\pi m_e})$ and η is the normalized potential relative to the wall.



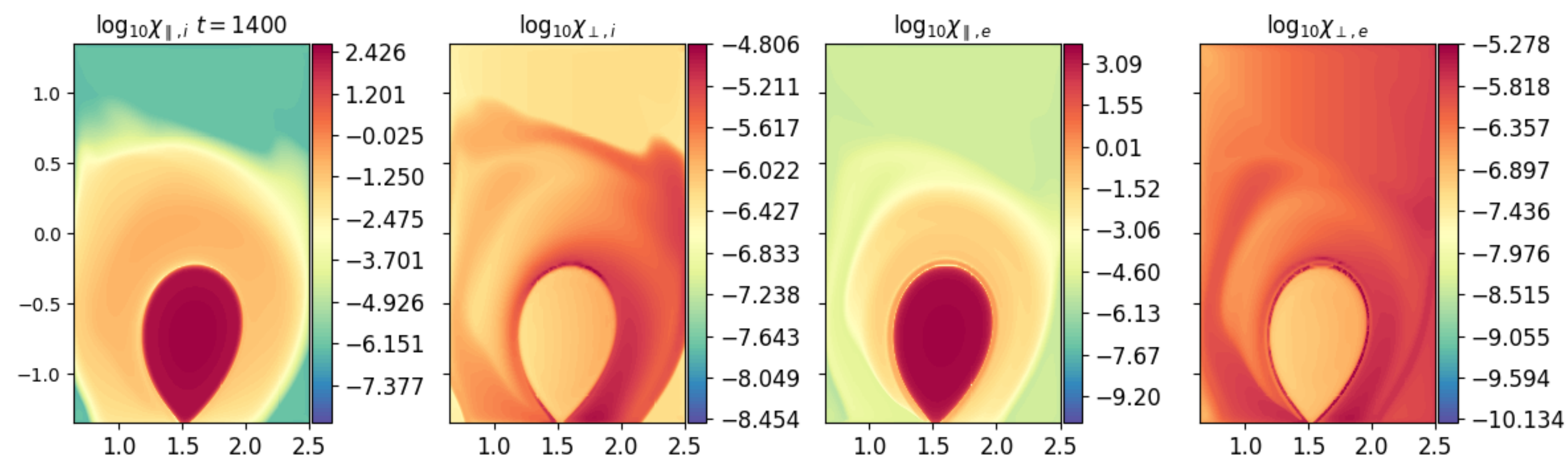
Magnetic presheath coordinate directions.

Closure relations include magnetization ($\Omega_c\tau$) effects.

- Magnetization effects had been implemented by John O'Bryan for Pegasus localized helicity injection modeling.

$$\chi_{\parallel,s} = \frac{T_s \tau_s}{m_s}\frac{\gamma_{0,s}}{\delta_{0,s}} \qquad \tau_e = \frac{12\pi^{3/2}\sqrt{m_e}(k_B T_e)^{3/2}\epsilon_0^2}{\sqrt{2}n_e e^4 \ln\Lambda}$$

$$\chi_{\perp,s} = \frac{T_s \tau_s}{m_s}\frac{\gamma_{1,s}x_s^2 + \gamma_{0,s}}{x_s^4 + \delta_{1,s}x_s^2 + \delta_{0,s}} \qquad \tau_i = \frac{12\pi^{3/2}\sqrt{m_i}(k_B T_i)^{3/2}\epsilon_0^2}{n_e e^4 \ln\Lambda}$$



Spatial variation of Braginskii conductivity coefficients when modeling edge-plasma conditions of order 1 eV.

- Computations with the MPS boundary conditions + Braginskii closures are being sorted out.

Conclusions

- NSTX VDE benchmark now includes first NIMROD results.
  - Behavior is similar M3D-C1 and JOREK results.
  - Faster thermal decay needs further investigation.
- VDE modeling with sheath and edge-plasma modeling close to production ready.