Effect of M3D-C1 Boundary Conditions on Flow

by

Brendan C. Lyons[1], C.C. Kim[2], S.C. Jardin[3], N.M. Ferraro[3]

[1]General Atomics

[2]SLS2 Consulting

[3]Princeton Plasma Physics Laboratory

September 13th, 2021

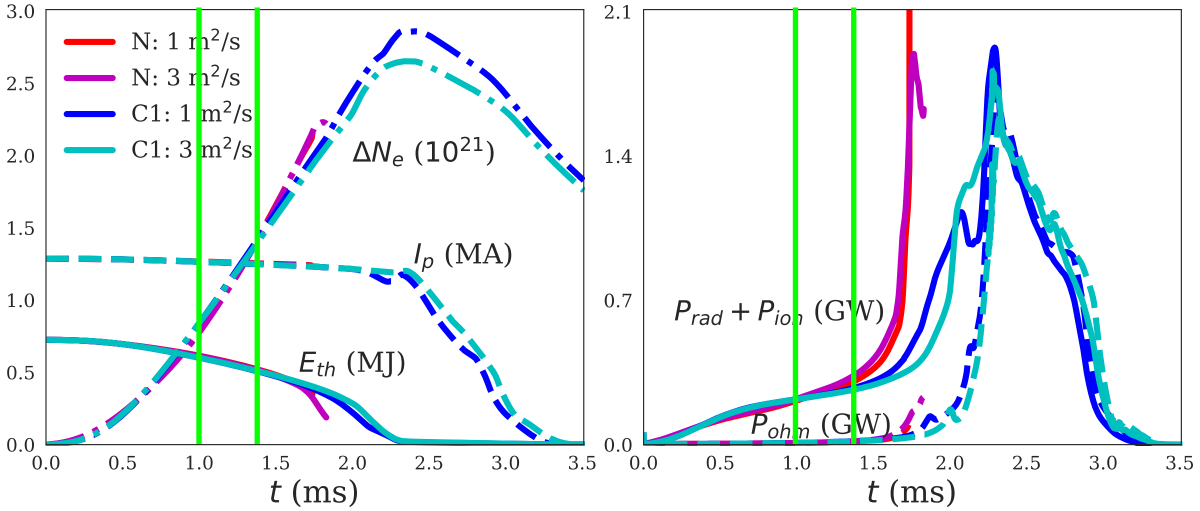
GENERAL ATOMICS

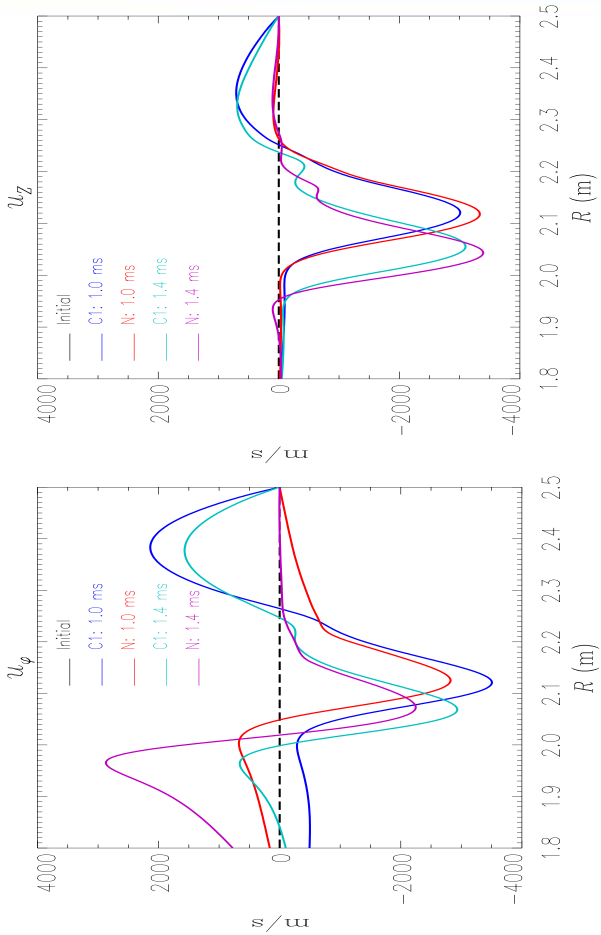
M3D-C1 and NIMROD are Seeing Very Different Flow Patterns

- **M3D-C1 no-flow boundary conditions are causing unphysical flows in simulations with large density sources**
  - First observed in 3D pellet benchmark
  - Subsequently seen in simplified tests
- **M3D-C1 observes open-field-line region (OFLR) flow is opposite sign of outflow from source**
- **NIMROD observes flow entrained with outflow from source**

Difference in 3D Pellet Benchmark Likely Caused by Flow

- **M3D-C1 seeing later radiation spike and coincident MHD instability onset**
- **Flow pattern strikingly different even before time traces diverge, especially in open-field-line region (OFLR)**





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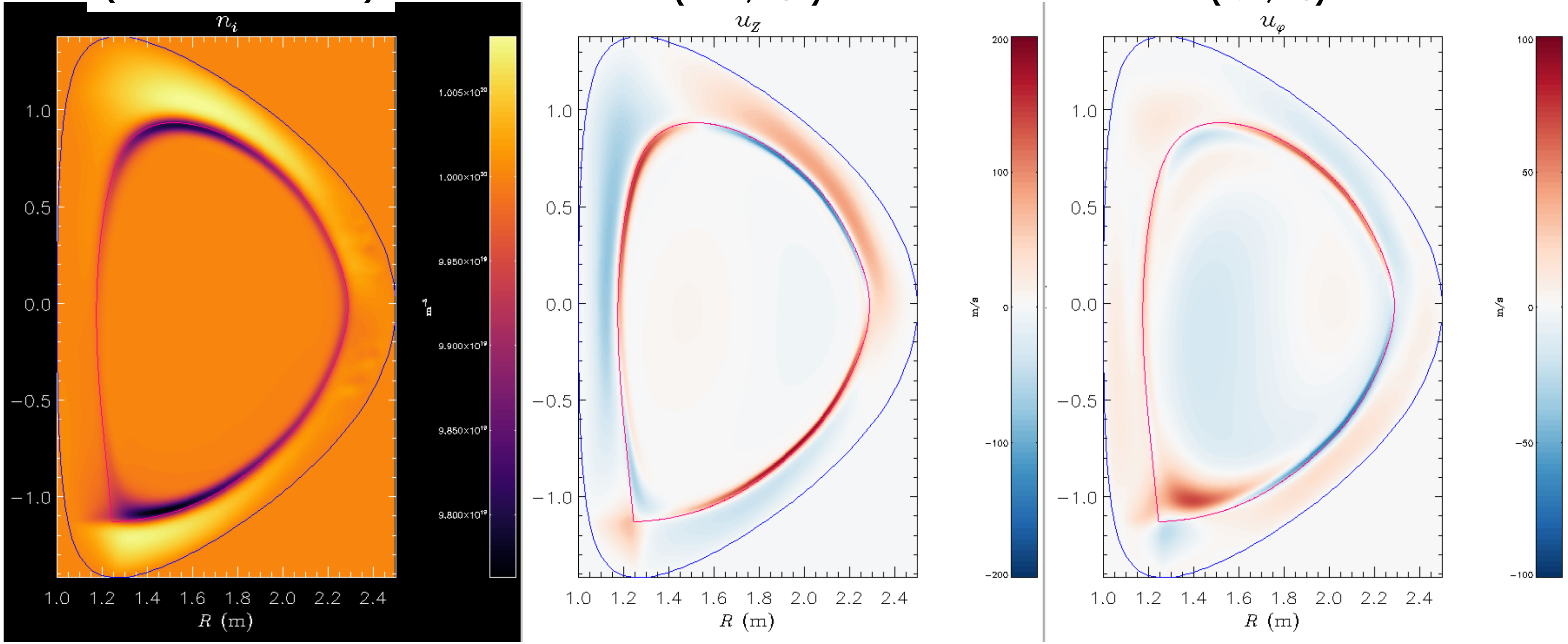
Simulation Without Source Gives Similar Results Between Codes

Some structure right at LCFS and reverses in OFLR

(9.76e19, 1.008e20) **(-149, 187)** **(-72, 70)**



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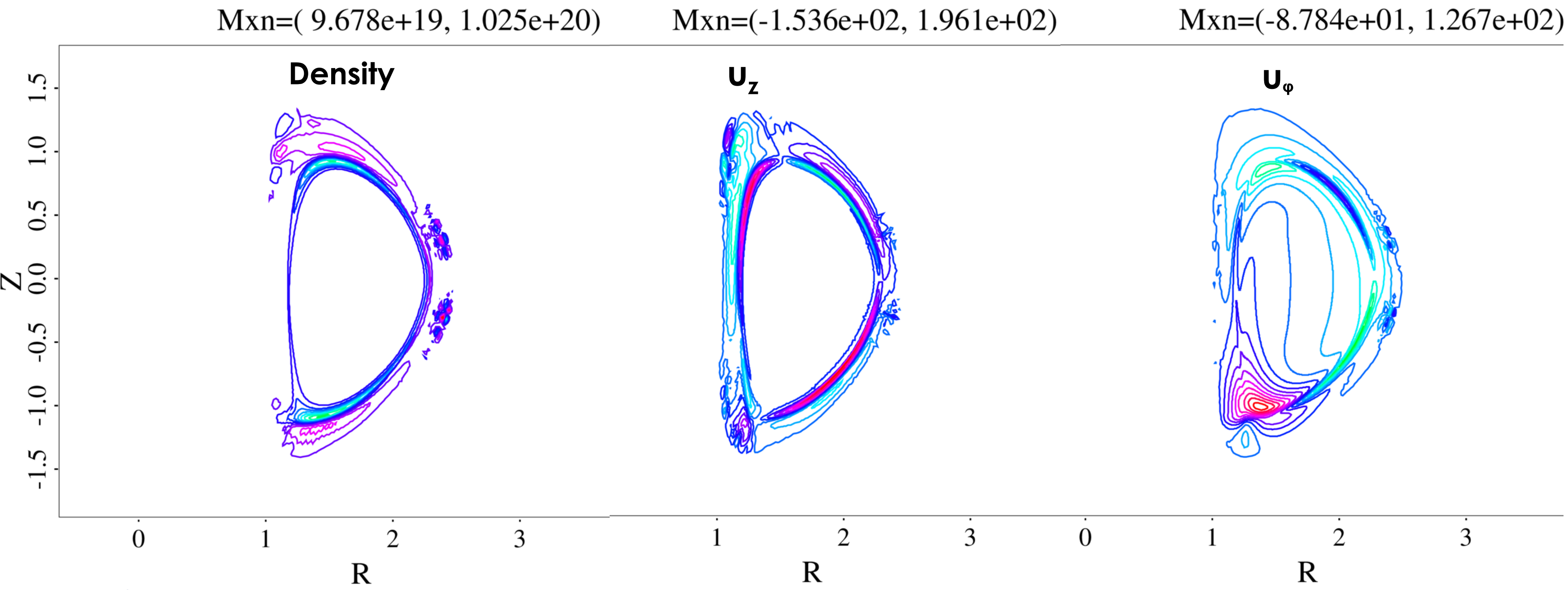
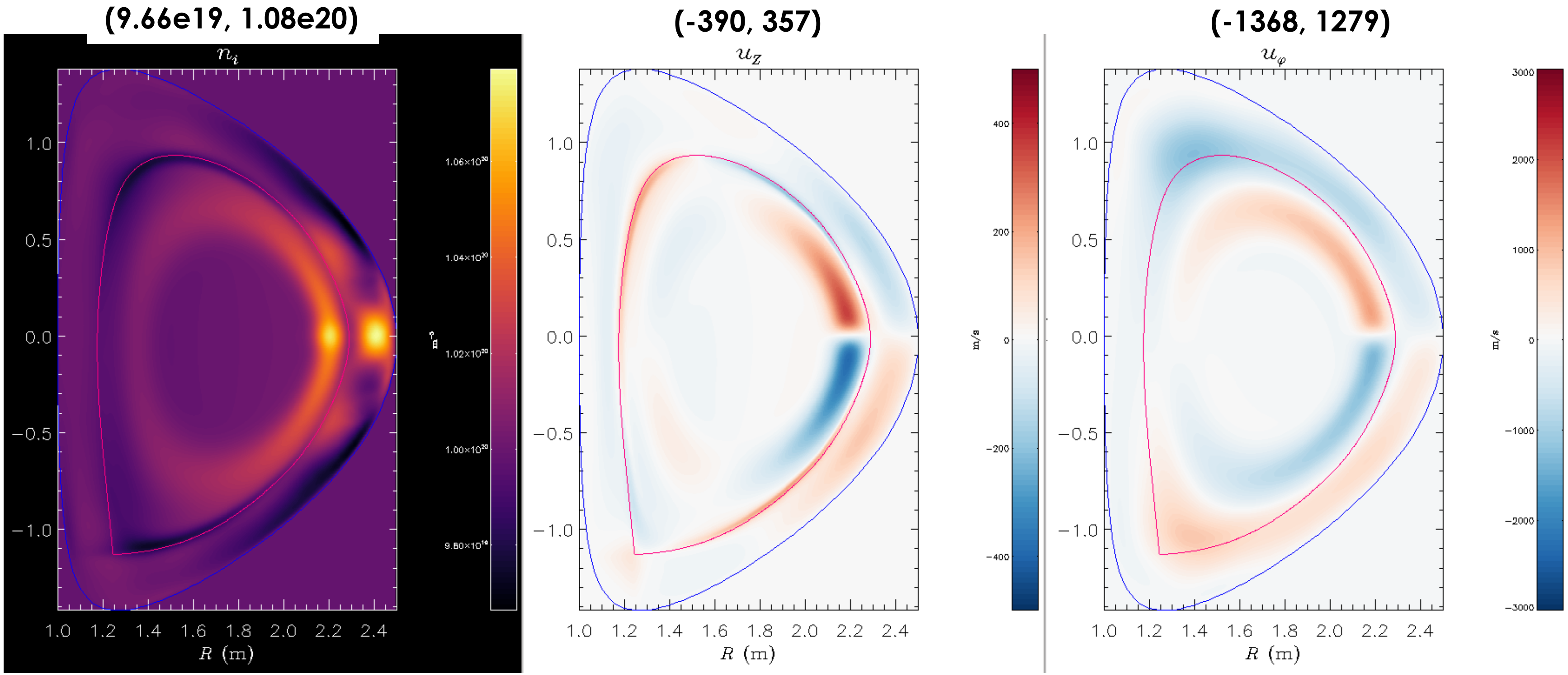
Simulation Without Source Gives Similar Results Between Codes

Same structure, but toroidal flow magnitude different (resolution difference?)



Stationary Source at 2.2 m Reproduced Flow Discrepancy

M3D-C1: Strong parallel outflow from source, but return flow near X-points & in OFLR



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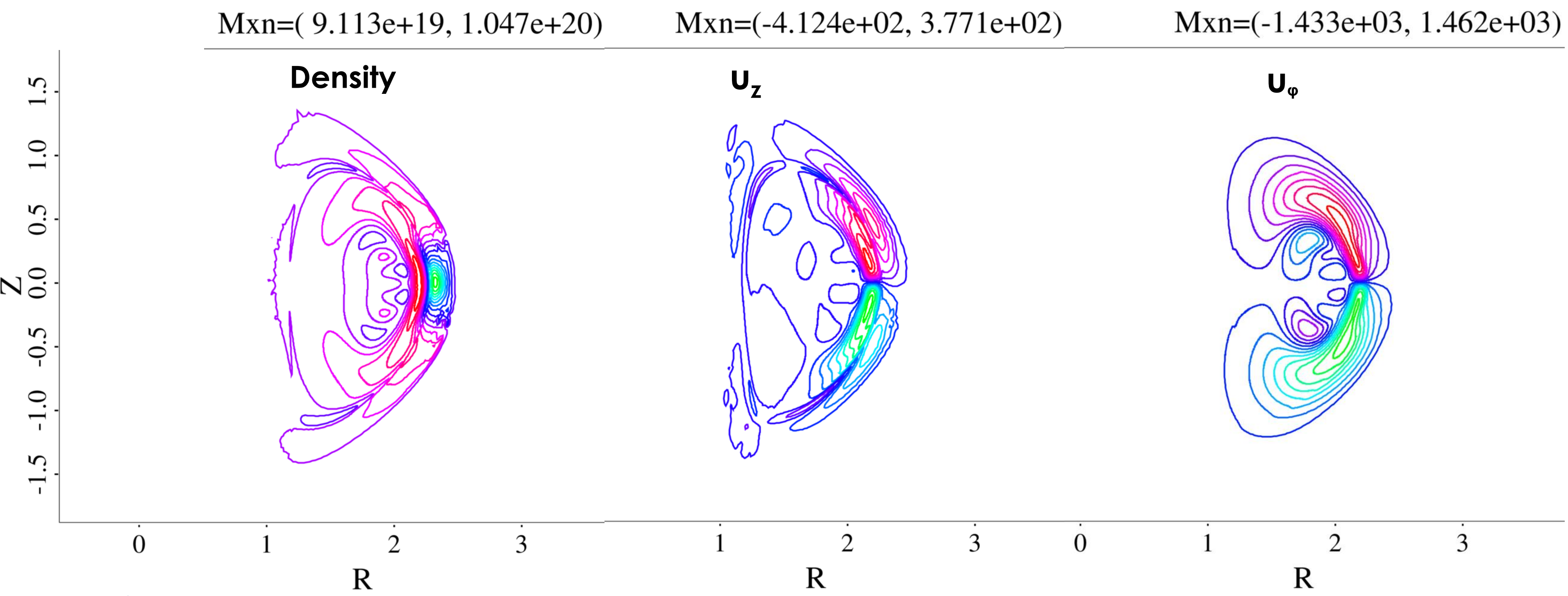
Stationary Source at 2.2 m Reproduced Flow Discrepancy

NIMROD: Similar outflow magnitude, but no return flow (same direction in OFLR)



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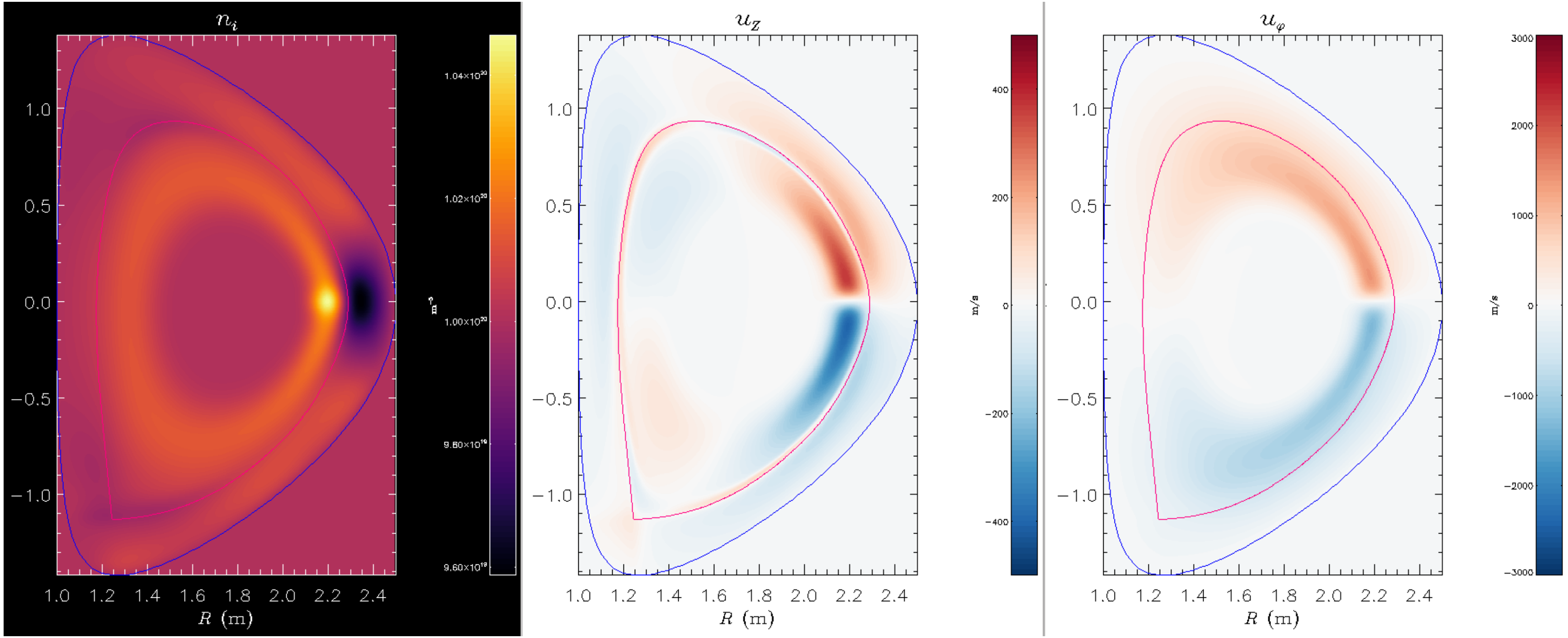
M3D-C1 Results With Poloidal Slipping Allowed Look Much More Similar to NIMROD



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M3D-C1 No-Flow Boundary Conditions Force Vorticity and Compression Components of Velocity to Zero Separately

- **M3D-C1 use a potential formulation for velocity**

$$\vec{u} = R^2 \nabla U \times \nabla\varphi + R^2 \omega \nabla\varphi + \frac{1}{R^2}\nabla_\perp \chi$$

- **Boundary conditions come from components of this**
  - No toroidal slipping (`inoslip_tor=1`): $\omega = 0$
  - No poloidal slipping (`inoslip_pol=1`): $R\frac{\partial U}{\partial n} + \frac{1}{R^2}\frac{\partial \chi}{\partial \tau} = 0$
  - No normal flow (`inonormalflow=1`): $-R\frac{\partial U}{\partial \tau} + \frac{1}{R^2}\frac{\partial \chi}{\partial n} = 0$
- **The second two are currently implemented such that each term is zero, not the sum**
  - No poloidal slipping: $\partial U/\partial n = 0 \quad \text{and} \quad \chi = 0$
  - No normal flow: $U = 0 \quad \text{and} \quad \partial \chi/\partial n = 0$
- **This was likely unseen before because χ typically small**

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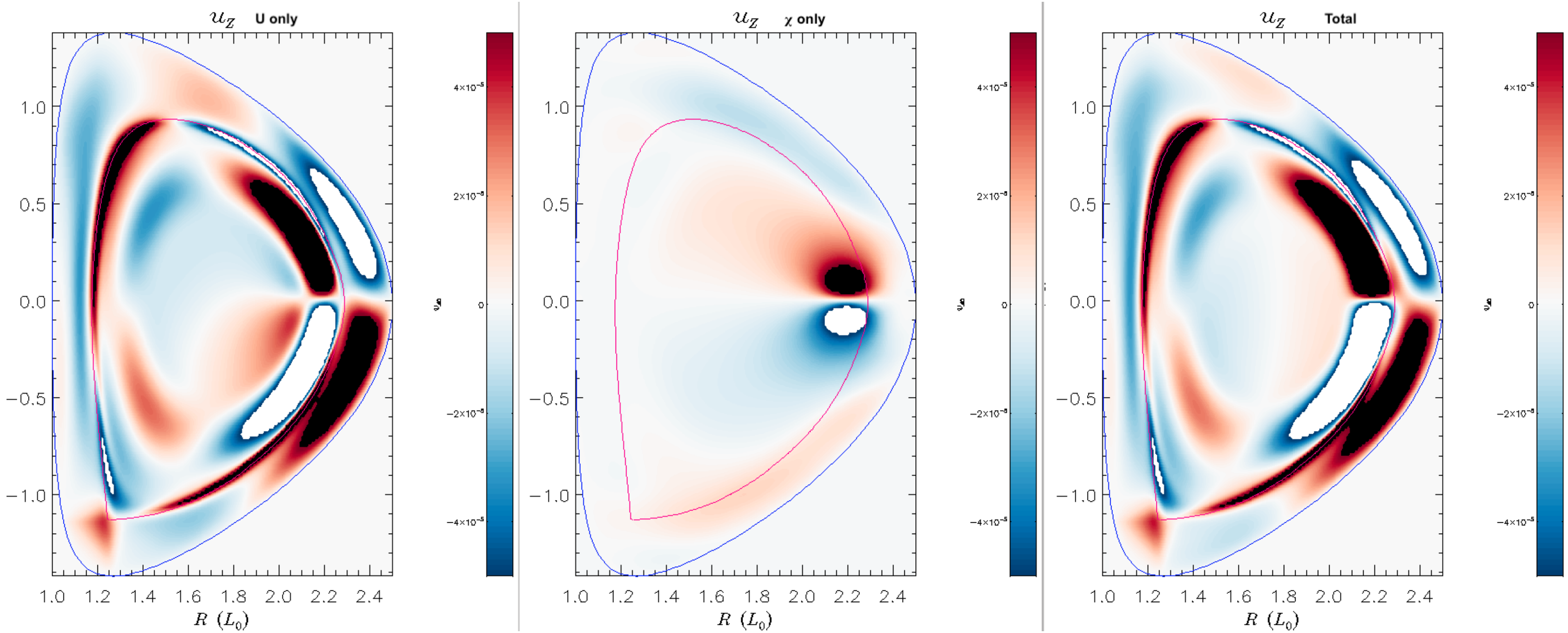
So With No-Slip and No-Normal Flow, Terms are Separately Zero

Flow Components For No-Slip



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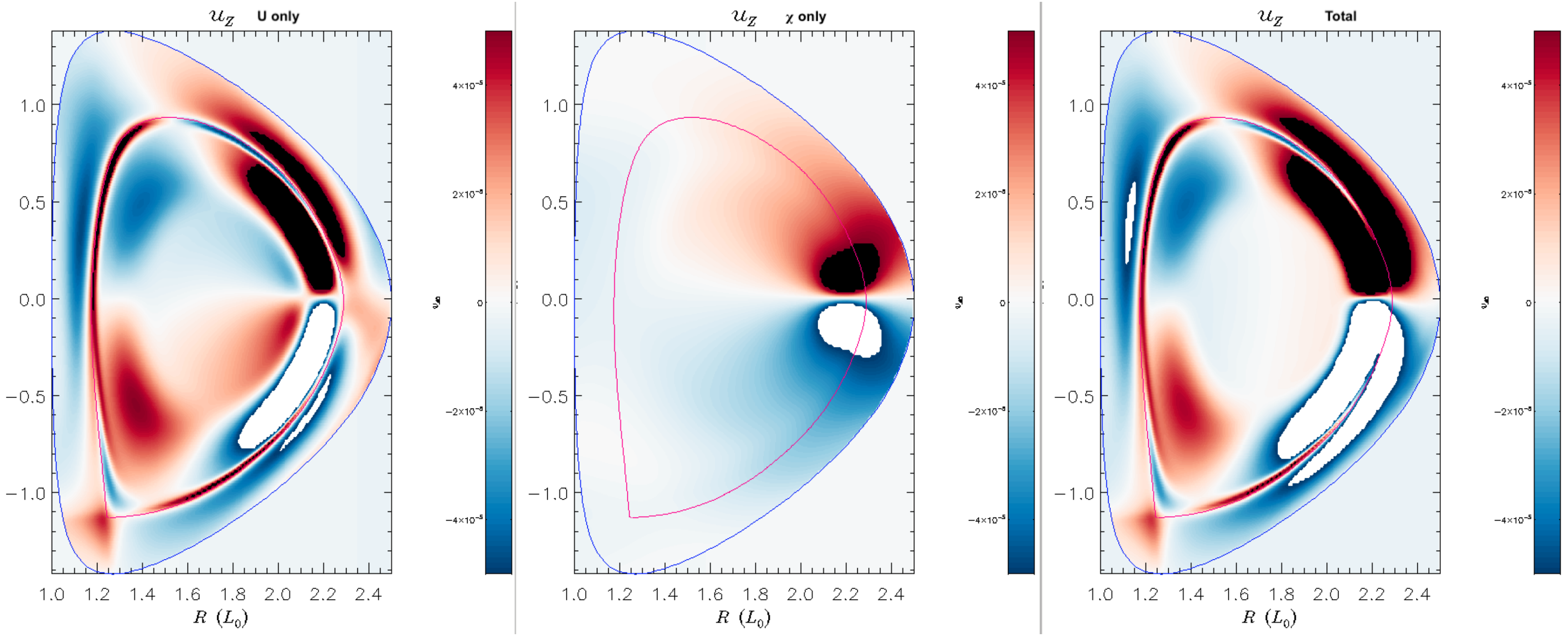
But They Shouldn't Be… Just Their Sum

Flow Components For Slipping



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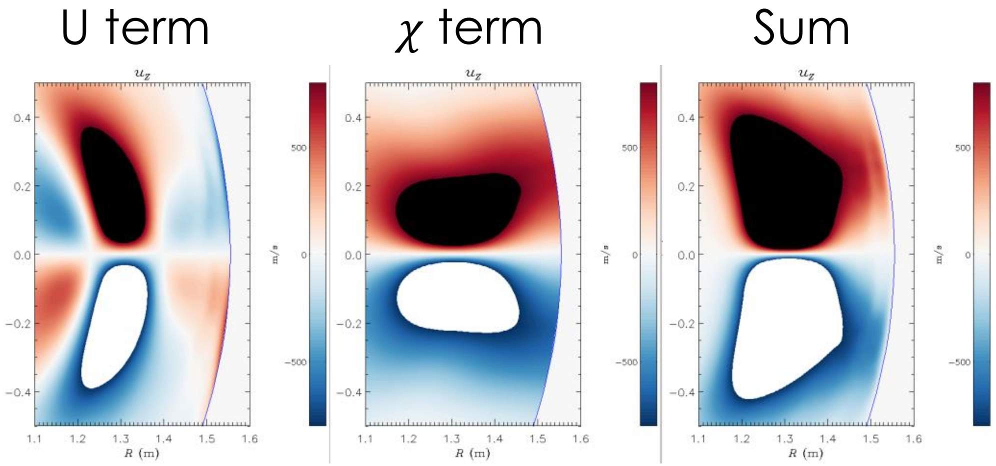
Fix In-Progress, But New Boundary Conditions are Unstable

- **Seems to be working alright before instability (i.e., properly coded) but should be confirmed**
- **Cause of numerical instability?**
  - Regularization?
  - Fewer BCs (4 → 2)
  - How to stabilize while maintaining physical solution



Some Final Thoughts

- N.B. This issue exists for some of the magnetic field BCs and needs to be fixed there too
- Could this affect VDE simulations? Seems like flow on the boundary would be important there
- Seems to suggest trouble using reduced MHD (e.g., JOREK includes parallel, compressible flow, but not perpendicular)