M3D-C1 with Corrected Poloidal Flow

by

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

[1]General Atomics

[2]Princeton Plasma Physics Laboratory

[3]SLS2 Consulting

September 22nd, 2021

GENERAL ATOMICS

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: $R\frac{\partial U}{\partial n} + \frac{1}{R^2}\frac{\partial \chi}{\partial \tau} = 0$
  - 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 (`inoslip_pol=1`): $\partial U/\partial n = 0 \quad \text{and} \quad \chi = 0$
  - No normal flow (`inonormalflow=1`): $U = 0 \quad \text{and} \quad \partial \chi/\partial n = 0$
- **This was likely unseen before because χ typically small**

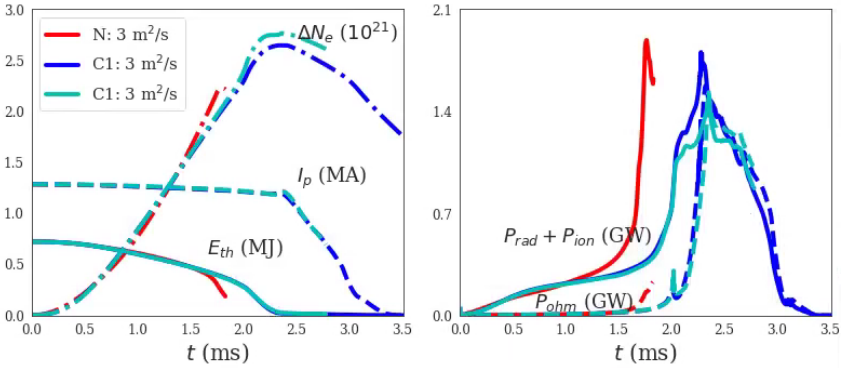
New, Correct Boundary Conditions Implemented, but Not Robust

- **Summed boundary conditions implemented as `inoslip_pol=2` and `inonormalflow=2`**
- **Using both is unstable (perhaps not enough constraints?)**
- **`inoslip_pol=2` and `inonormalflow=1` is sometimes stable**
  - Amounts to 3 BCs: $R\frac{\partial U}{\partial n} + \frac{1}{R^2}\frac{\partial \chi}{\partial \tau} = 0\,, \quad U = 0 \quad \text{and} \quad \partial\chi/\partial n = 0$
  - Value of χ not fixed
  - Requires stronger regularization

New Poloidal Flow Boundary Condition Does Not Siginicantly Change 3D Benchmark Results

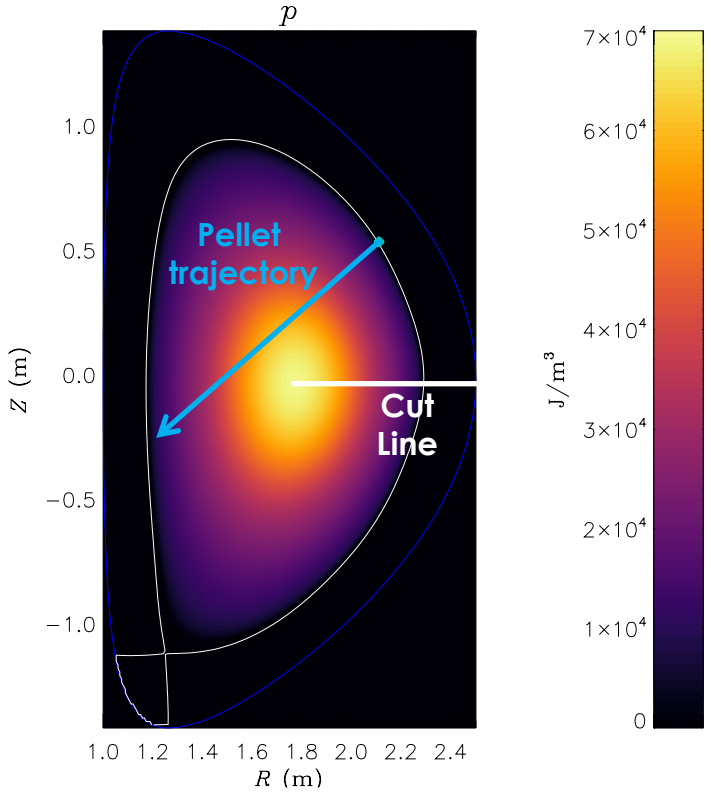
- Reran with old normal flow condition but new poloidal flow condition
- Increased regularization (`regular=1e-4` vs `1e-6`)
- Near identical time histories, despite change in velocity profiles (see following slides)

Old (`inoslip_pol=1`)
New (`inoslip_pol=2`)

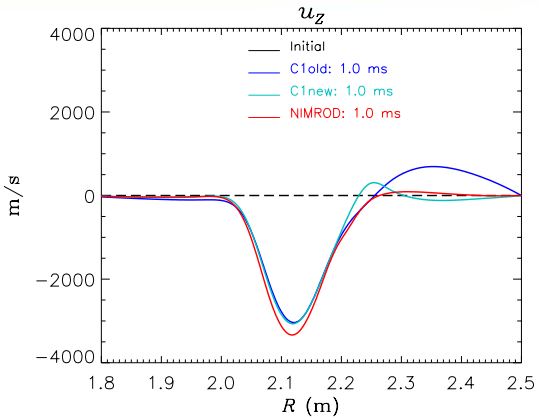


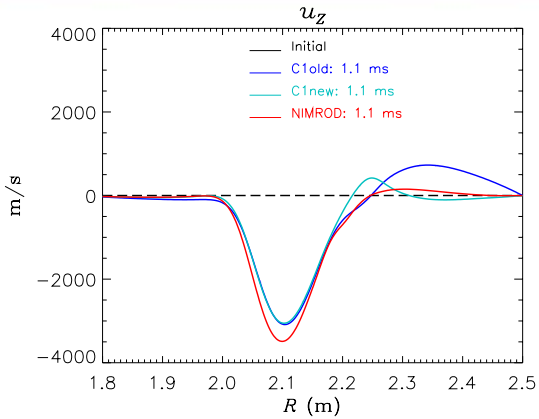
Comparison of Midplane Cuts

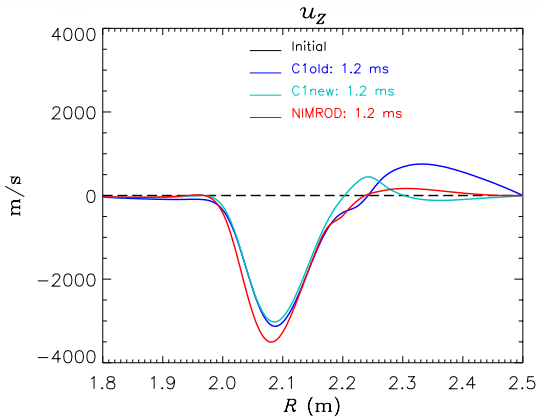
- Cuts are taken through midplane
- Downstream of pellet location
- R components roughly normal
- Z components roughly poloidal

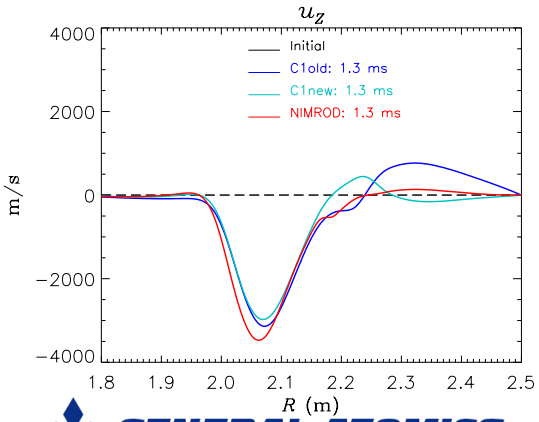


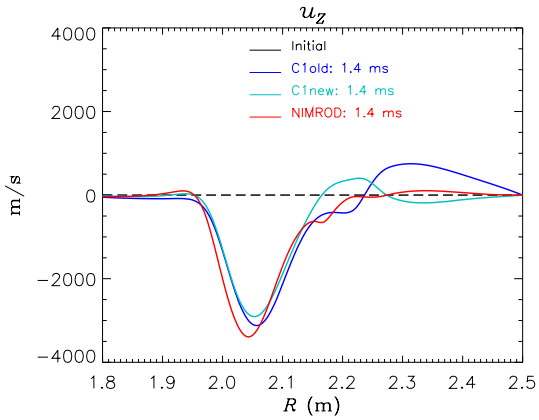
Poloidal Flow Better but Not Perfect

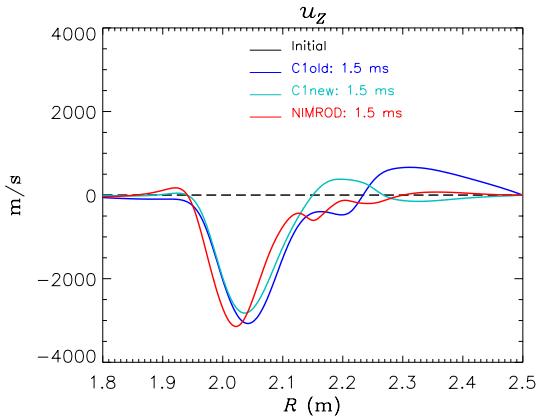






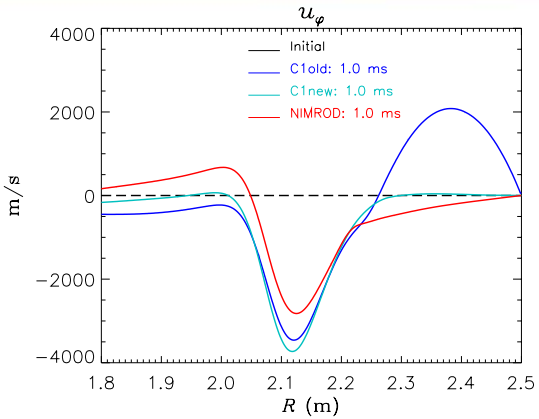


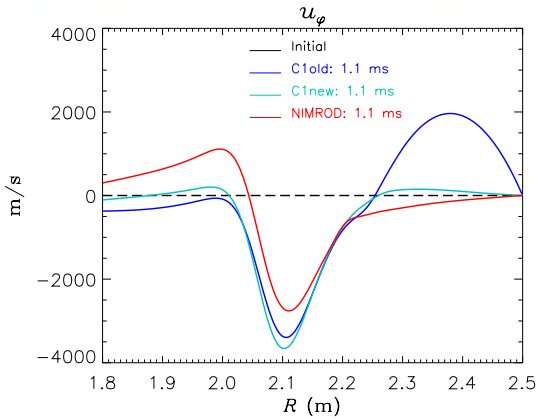


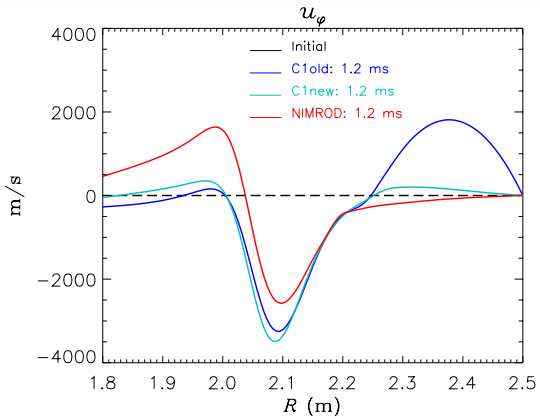


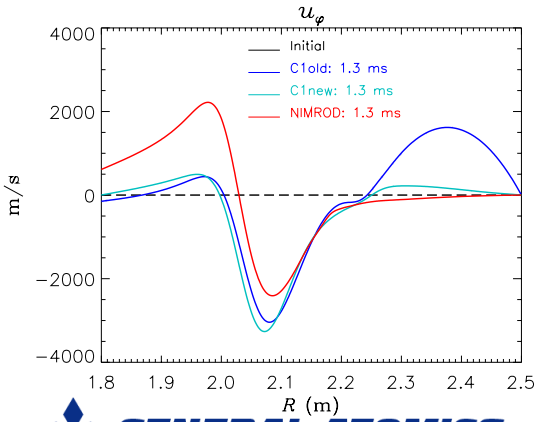
GENERAL ATOMICS

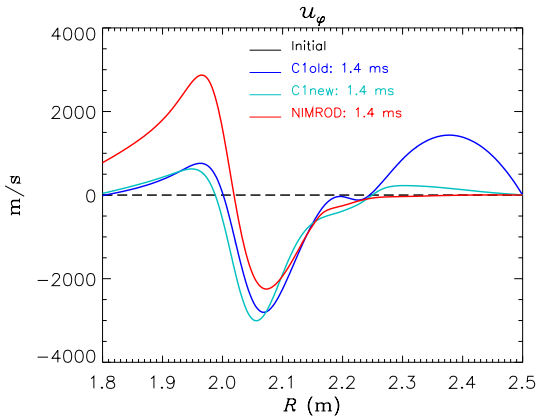
Toroidal Flow Better in Edge, but Differs in Core

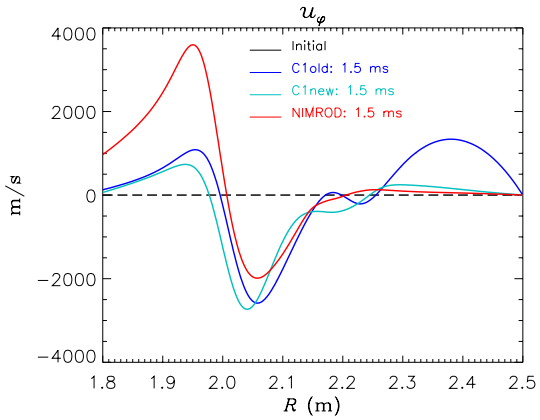






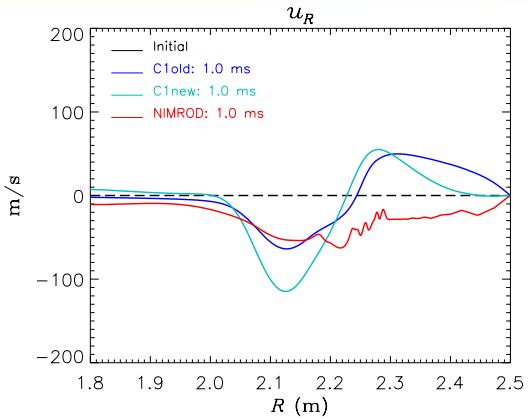


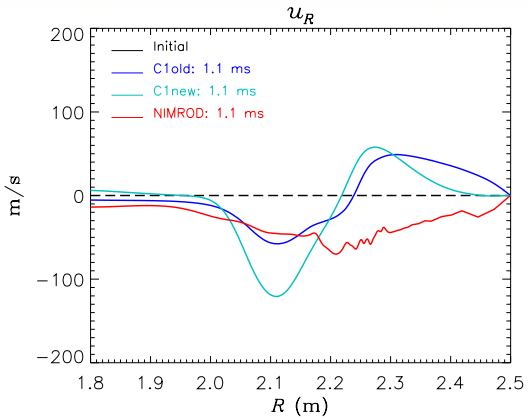


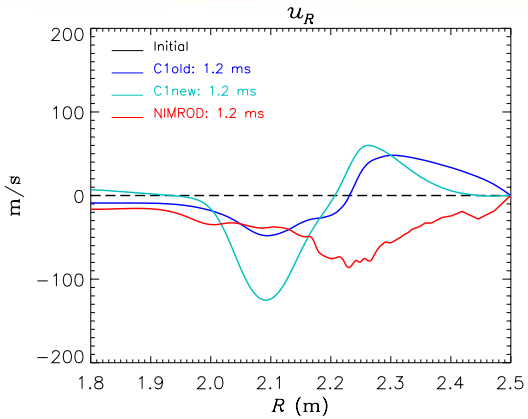


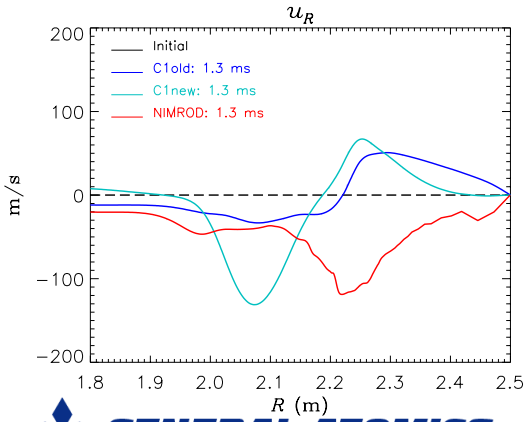
GENERAL ATOMICS

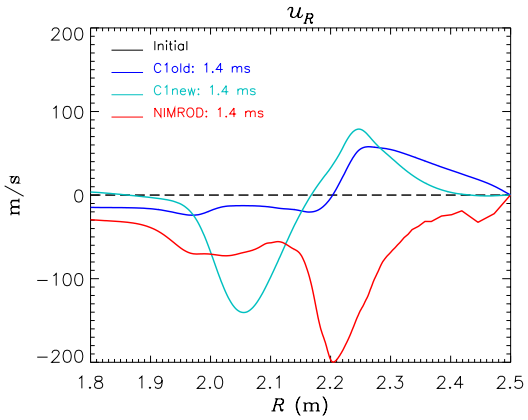
Radial Flow Still Very Different (NIMROD Has Single Sign)

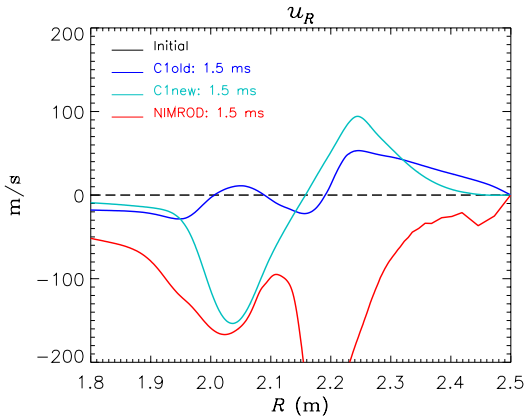






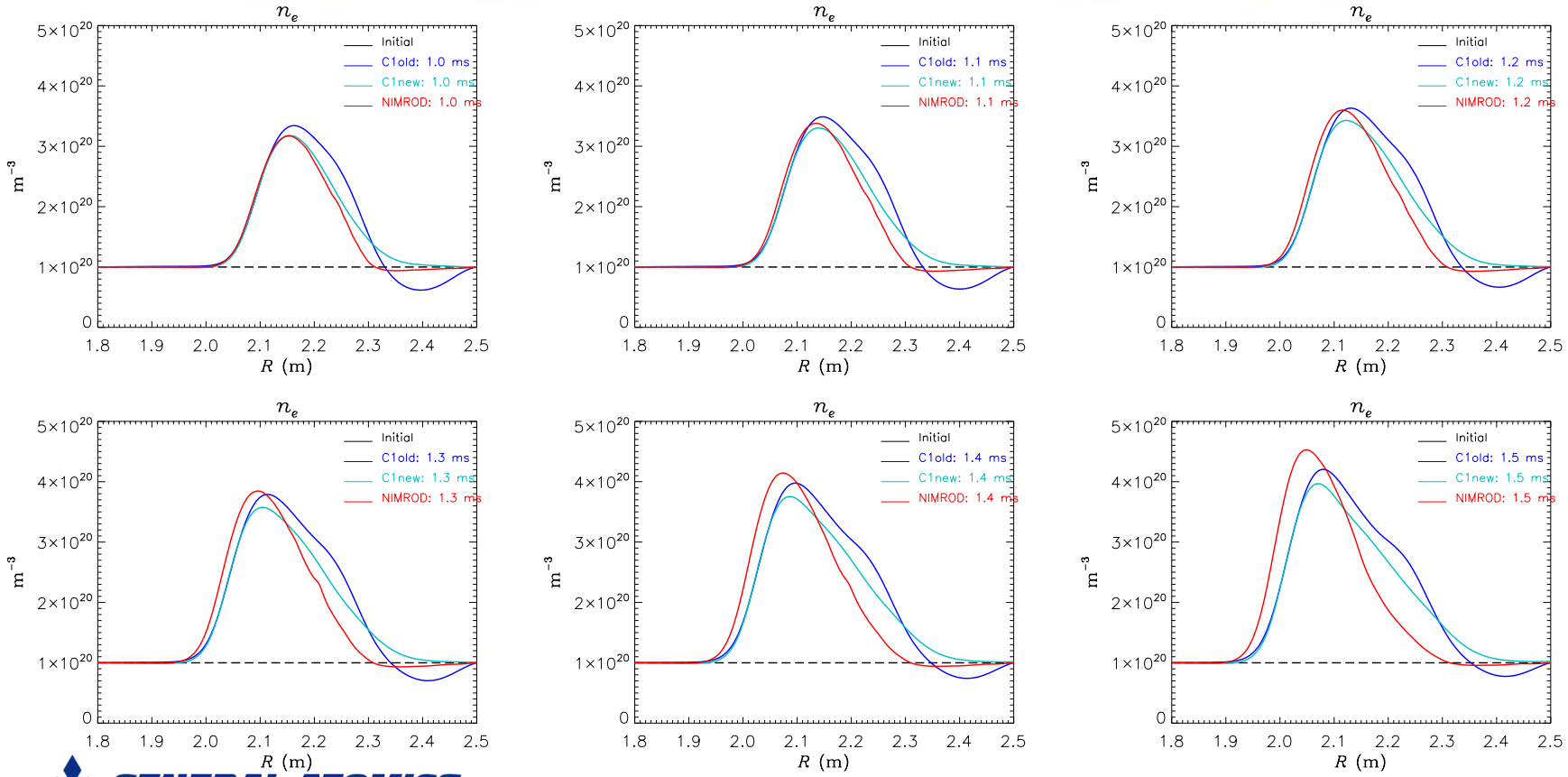






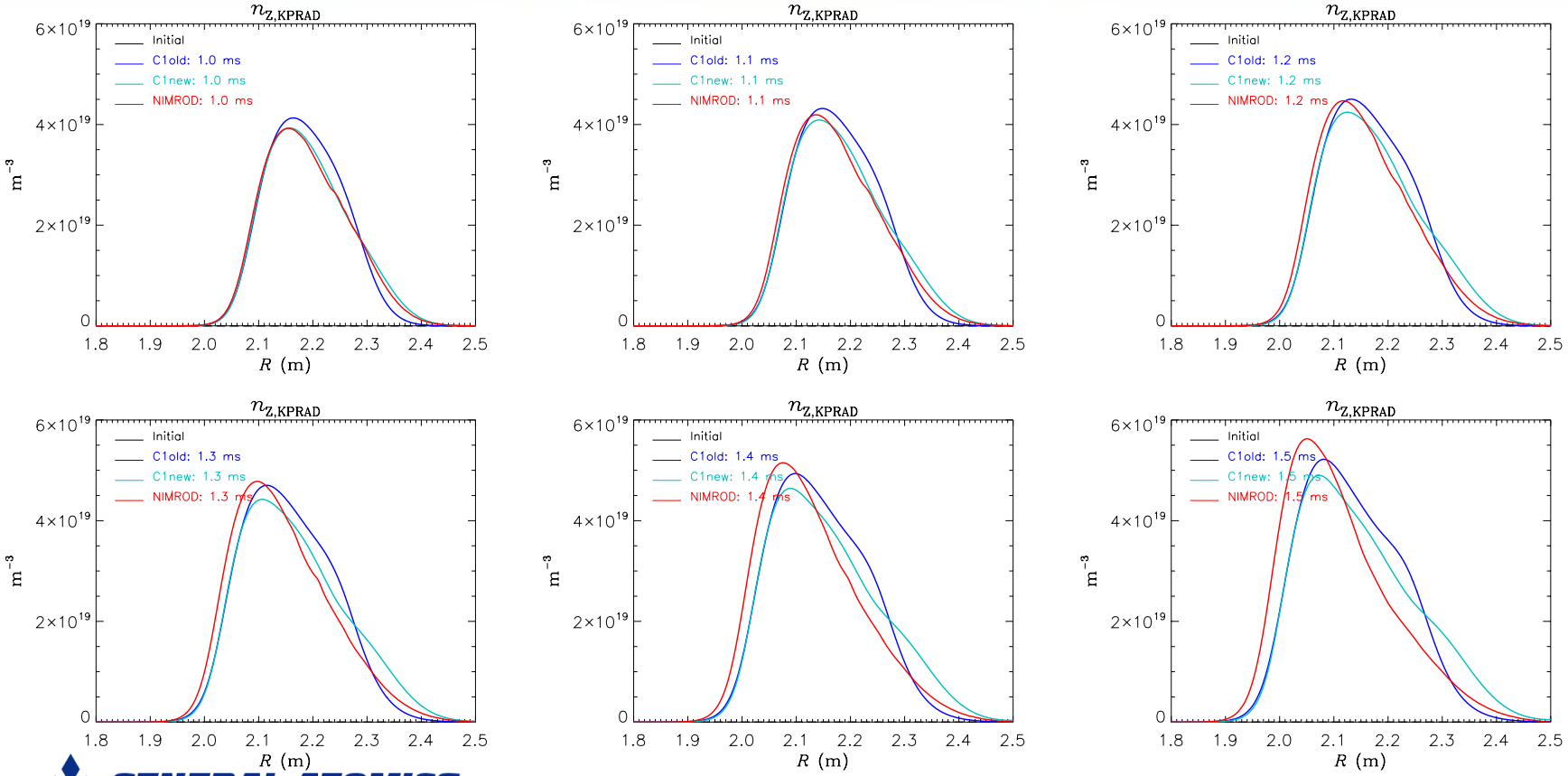
GENERAL ATOMICS

Electron Density in Good Agreement Early, But Diverges



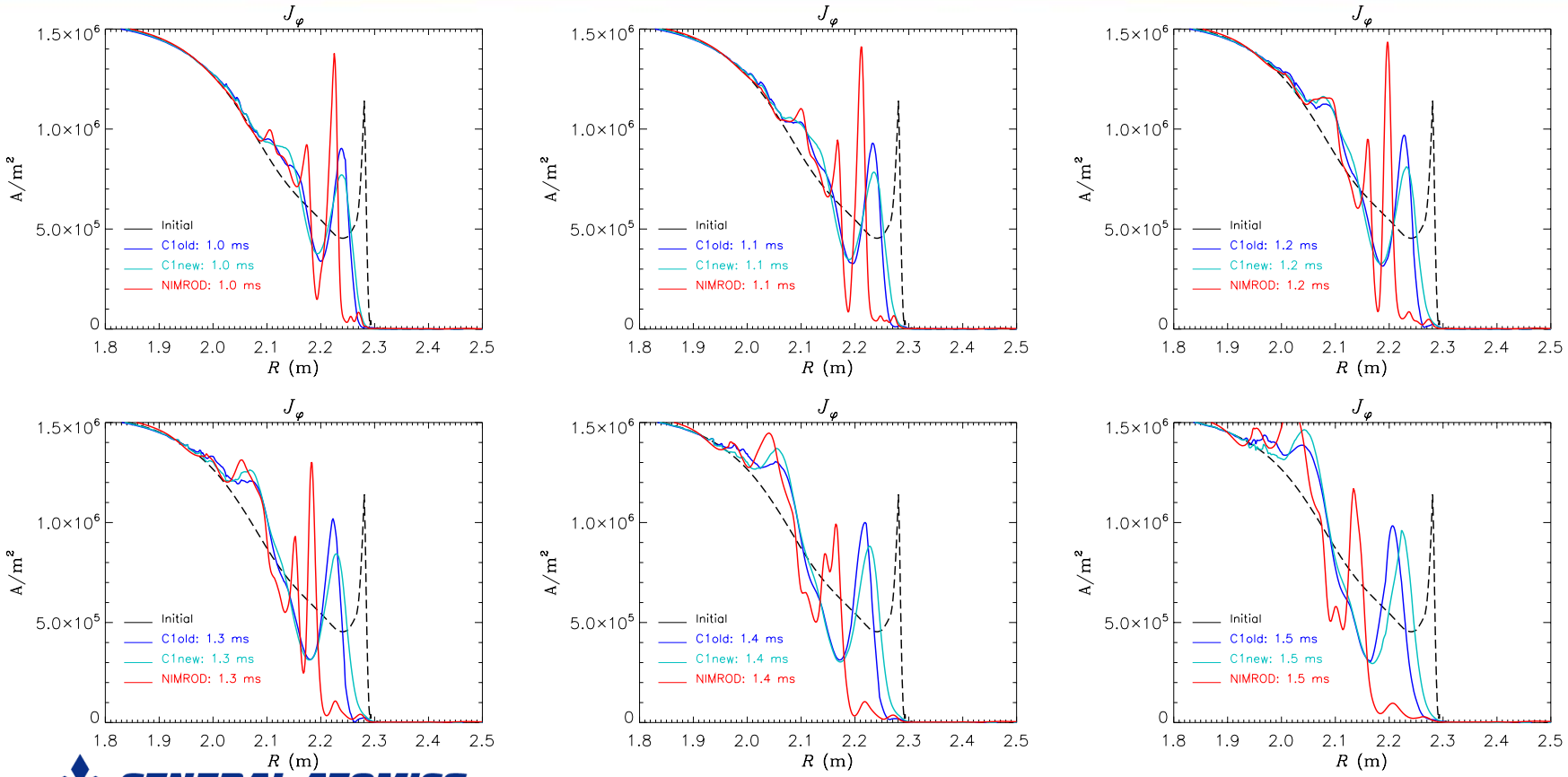
GENERAL ATOMICS

Impurity Density in Even Better Agreement Early, But Diverges



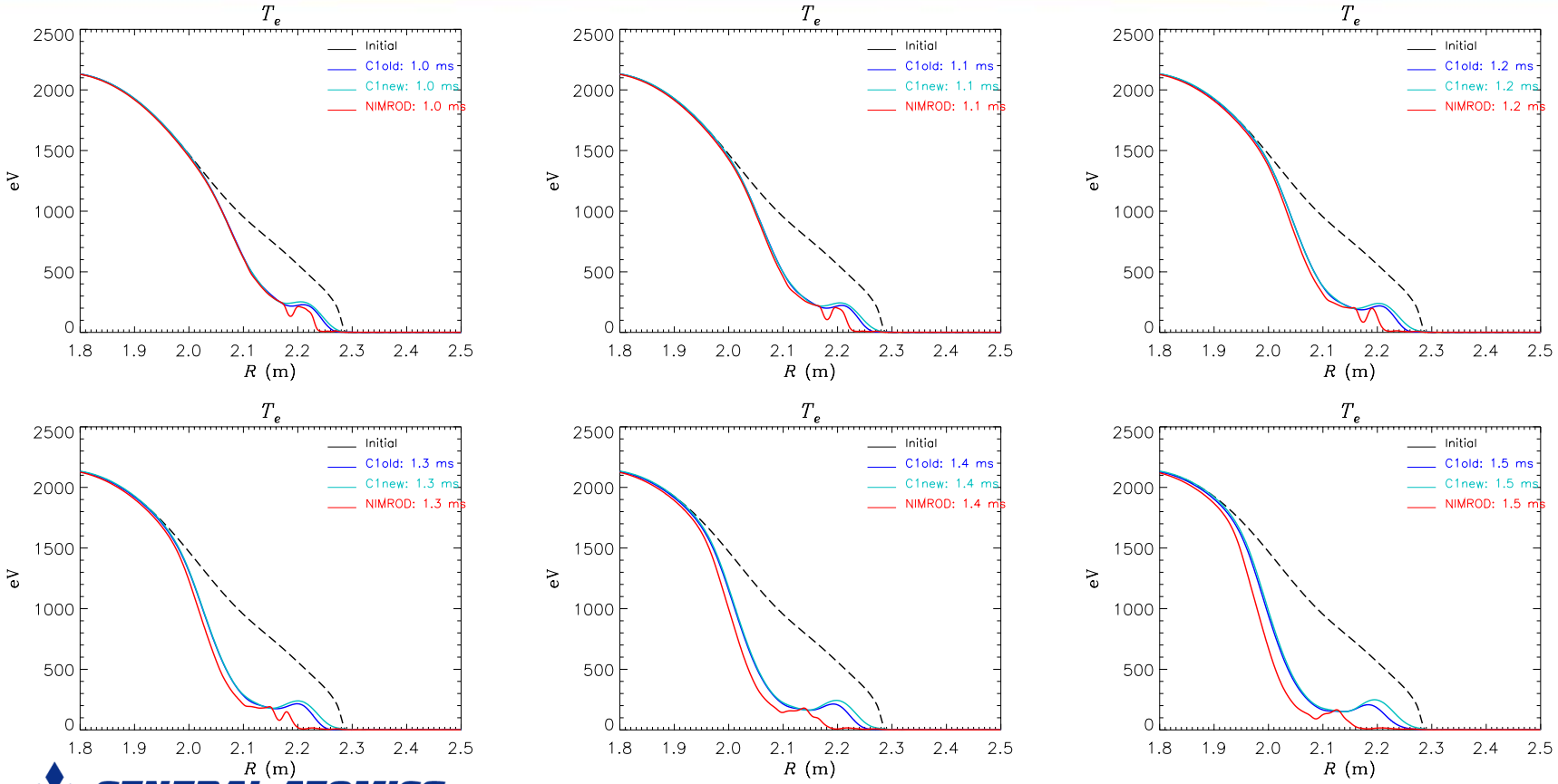
GENERAL ATOMICS

Toroidal Current Density Still Very Different



GENERAL ATOMICS

Temperature Consistent with Current Discrepancies



Some Thoughts

- **Radial flow is small but clearly very different**
  - NIMROD radial flow has single sign, and grows in amplitude
  - Early kinking of plasma inward at φ=0?
- **Charlson pointed out that the gradient of the flow at the boundary appears opposite between M3D-C1 and NIMROD**
- **Maybe we do need to get the normal flow condition correct, but how to do it stably?**
- **Maybe the difference in edge temperature and current is unrelated?**