

# M3D-C1 ZOOM Meeting

Announcements:

06/07/2021

## CS Issues

1. GPU solve status ... LBL
2. Mesh adaptation update
3. stellar.Princeton.edu -- range of solve times
4. NERSC Time
5. Changes to github master since last meeting DIII
6. Broke calculate\_ablation into two routines
7. Regression tests

## Physics Studies

1. Progress on SPI Modeling – Brendan Lyons
2. Other

**Note:** [meeting minutes posted on m3dc1.pppl.gov](http://m3dc1.pppl.gov)

Steve Jardin  
Hank Strauss  
Mark Shephard  
Addelle Wright  
Jin Chen  
Chang Liu  
Chen Zhao  
Seegyoung Seol  
Andreas Klinger  
Cesar Clauser  
Brendan Lyons  
Usman  
Priyankama Sinha  
Nate Ferraro  
Sam Williams  
Sherry Li  
Yang Liu

**In attendance**

# Announcements

- TSDW meeting July 19-23
  - Registration and abstracts due June 14
- APS Nov 8-12
  - Abstracts due by July 15

# GPU Solve status

- LBL to report

# Mesh Adaptation Update

RPI?

Brendan Lyons ?

# stellar.pppl.gov

Timing issue:

Adelle Wright sent me a case this morning where she ran the same case 2 times and got much different timings

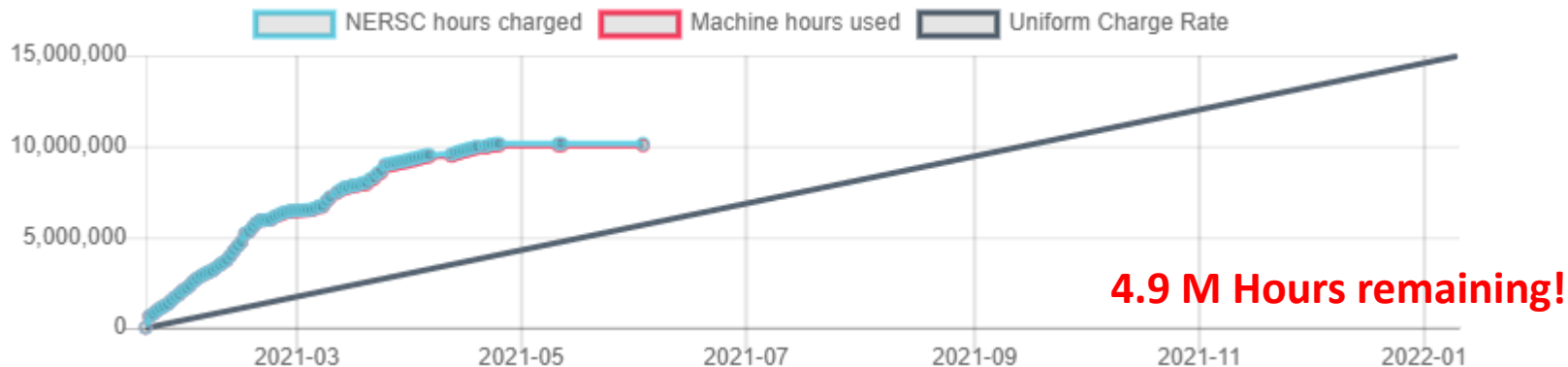
	case 1	case 2
Compute matrix elements	<b>100 s</b>	<b>100 s</b>
Solve matrix	<b>100 s</b>	<b>700 s</b>

This should be reported to [cses@princeton.edu](mailto:cses@princeton.edu) along with details on the slurm job #

(my job that had erratic timing is now running ok)

# NERSC Time

mp288



m3163

Closed for general use

- mp288 received 10M Hrs for CY 2021
- Initial allocation exhausted by May 1
- John Mandrekas (DOE) added 5M Hrs additional
- More time may be possible if this is exhausted
- Pearlmutter time will not be charged for this FY

# Changes to github master since 05/16

- **Nate Ferraro**
  - **06/03/21:** Incremented release version to 1.14-devel in master
- **Steve Jardin**
  - **06/07/21:** Broke calculate \_ablation into two routines



# Broke calculate\_ablation into two routines

At restart:

call rdrestart\_hdf5 (reads restart file at cycle ntime)

.....

.....

calculate\_ablation      calculates pellet ablation parameters  
.....                      and shrinks pellet radius by 1 time step (  $\sim dt * r_{p\dot{}}$  )

.....

call output                      (overwrites cycle ntime information)

**Now, calculate\_ablation → calculate\_ablation + pellet\_shrink. Only the former is called at restart time but both are called in time loop.**

**→ This solved the problem of getting different answers when restarting from same cycle.**

## Local Systems

- PPPL centos7(06/07/21)
  - 6 regression tests **PASSED** on centos7:
- PPPL greene (06/07/21)
  - 5 regression tests **PASSED on greene (m3dc1)**
- STELLAR (06/07/21)
  - 6 regression tests **PASSED** on stellar
- TRAVERSE(03/29/21)
  - Code compiles
  - Regression test failed: split\_smb not found in PATH

## Other Systems

- Cori-KNL (2/08/2021)
  - 6 regression tests passed on KNL
- Cori-Haswell (2/08/2021)
  - 5 regression tests passed
  - KPRAD\_RESTART did not pass, but differences are very small in velocity variables. All magnetic and thermal good. Similar difference as Cori-KNL
  - RMP\_nonlin initially failed ...: There was an error in partitioning the mesh, but passed on resubmission
- PERSEUS
  - All 6 regression tests PASSED on perseus (J. Chen, 9/04/20)
- MARCONI
  - All regression tests PASSED on MARCONI (J. Chen, 9/04/20)
- CORI GPU (10/26)
  - ??

**Brendan to update progress on SPI modeling**

That's All I have

Anything Else ?

## DIII-D Resistive Wall Mode

Email from Hank Strauss on 5/27/21

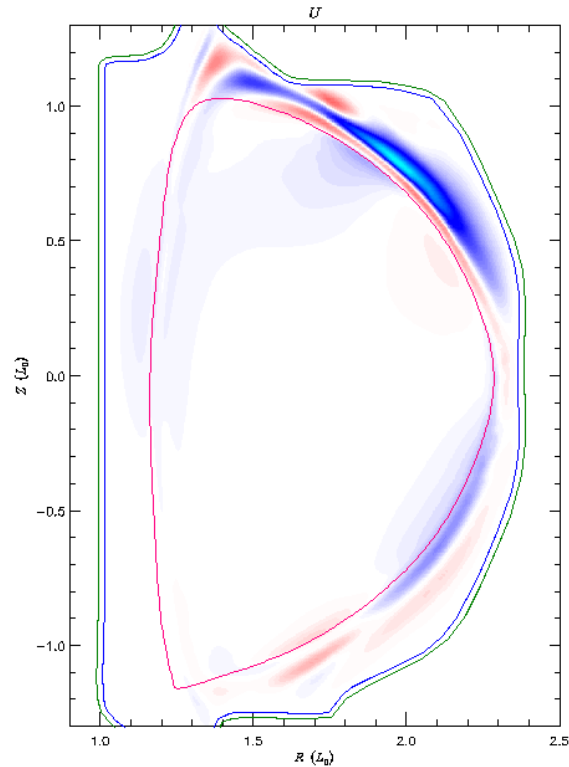
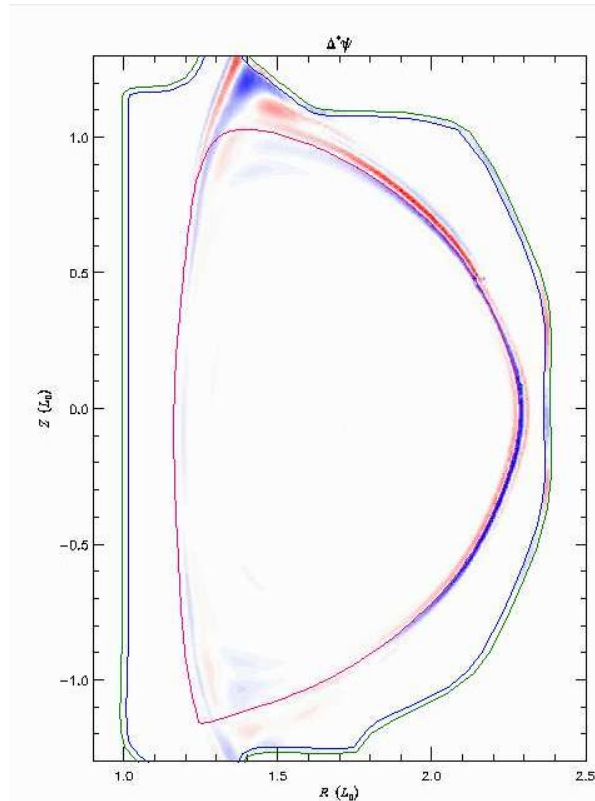
I tried to find D3D RWMs (RWTM)s with Brendan's mesh and C1input files, but it seems that the wall is behaving like an ideal wall. It needs much more adaptive refinement. I also tried a nonlinear run, but even though  $\epsilon > 0$ , it didn't have a 3D perturbation.

A linear run is in /scratch/gpfs/hs9956/d3d\_eb1\_1f\_eq\_l11 and nonlinear in rw1\_nl\_54576.03354\_945b2.

I think lack of resolution at the wall is also causing AVDE simulations to fail at small  $\eta_{\text{wall}}$ . The mesh needs adaptive refinement at the wall.

An ADVE simulation is in JETm3dc1\_0.12h9b4.

# Linear Eigenfunction



Physical mode? Not tearing.

# Chen Zhao paper on RE with sources

## Simulation of the runaway electron plateau formation during current quench

C. Zhao<sup>1</sup>, C. Liu<sup>1</sup>, S. C. Jardin<sup>1</sup>, N. M. Ferraro<sup>1</sup>, B. C. Lyons<sup>2</sup>  
V. Bandaru<sup>3</sup>, M. Hoelzl<sup>3</sup>

<sup>1</sup> Princeton Plasma Physics Laboratory, Princeton, NJ, United States of America

<sup>2</sup> General Atomics, San Diego, CA, United States of America  
General Atomics, San Diego, CA, United States of America

<sup>3</sup> Max Planck Institute for Plasma Physics, Boltzmannstraße, Garching, Germany

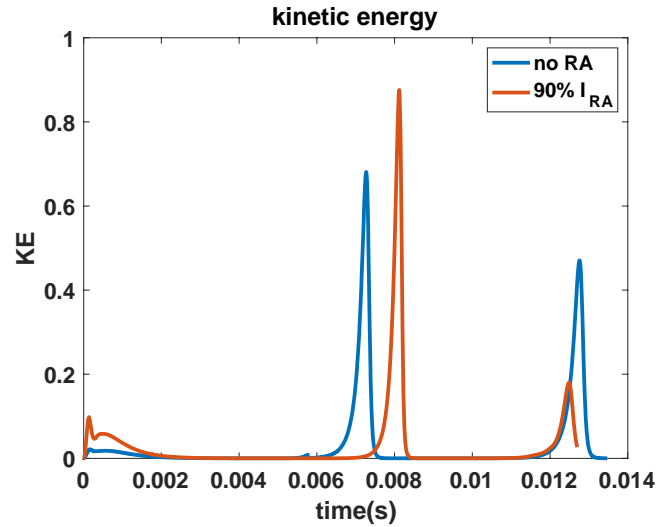
- Source terms and coupling to MHD
- Runaway source test case and benchmark with JOEKE
- Current quench result with DIII-D parameters



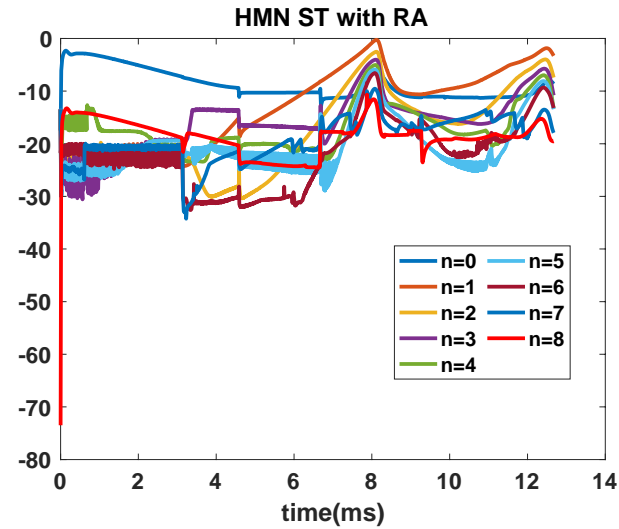
Isabel ST with RA

06/1/21

- Both cases are use Isabel eq with mesh 0.01m



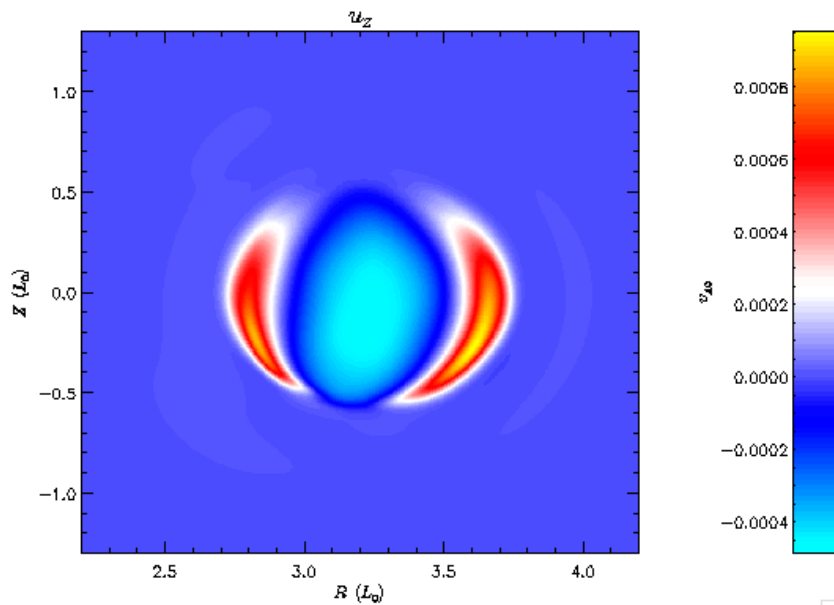
- It needs more time to see if there is only on ST phase with RA



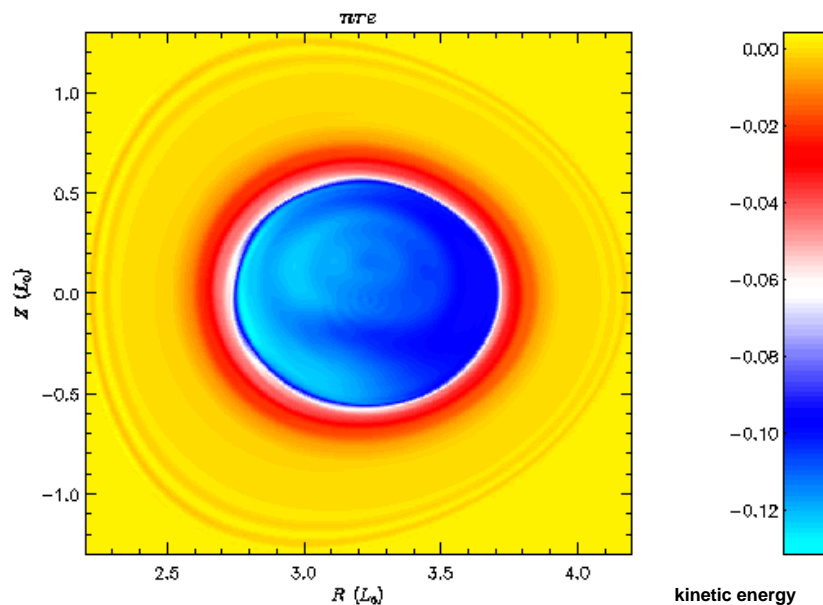
- Most unstable mode is  $n = 1$  with RA

# Profiles at 8ms with RA (1<sup>st</sup> ST phase)

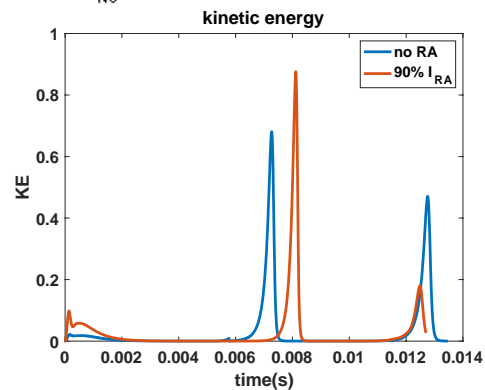
$V_z$



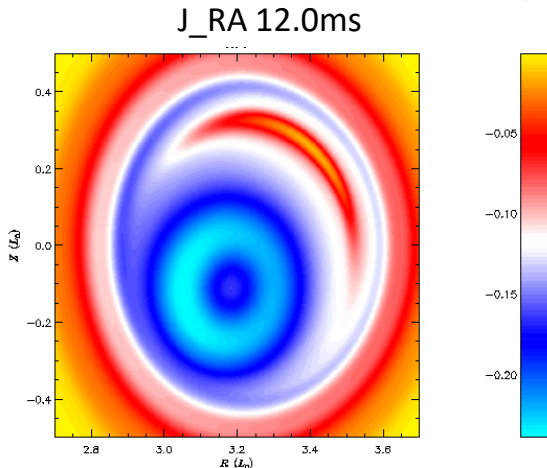
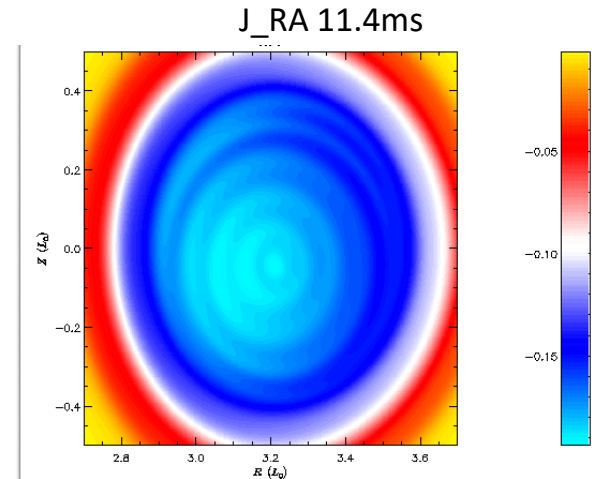
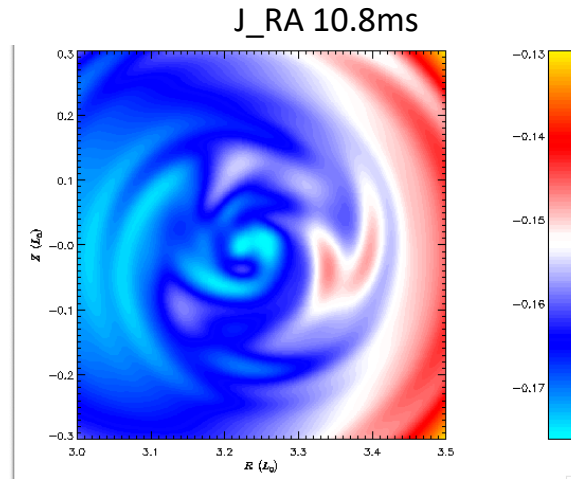
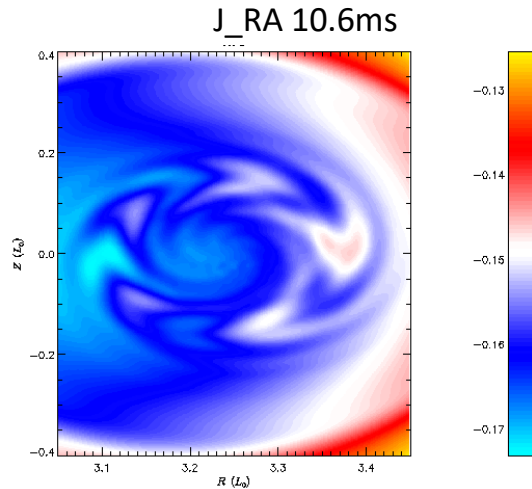
$J_{RA}$



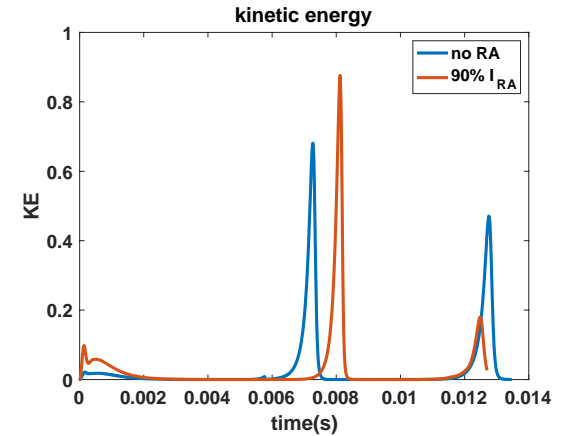
- No clear mode in runaway current



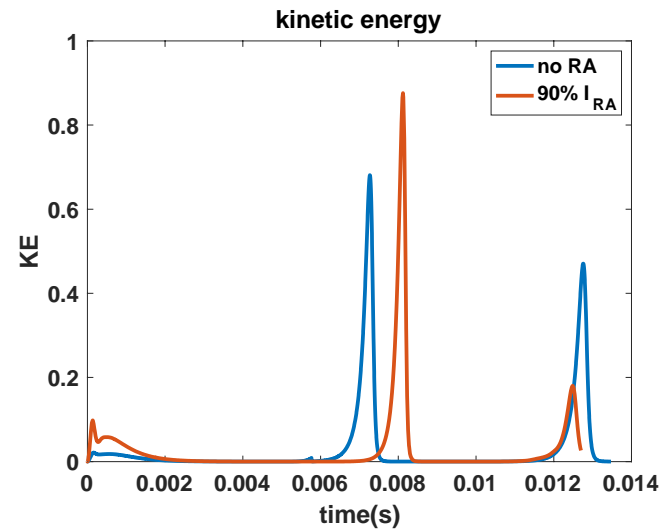
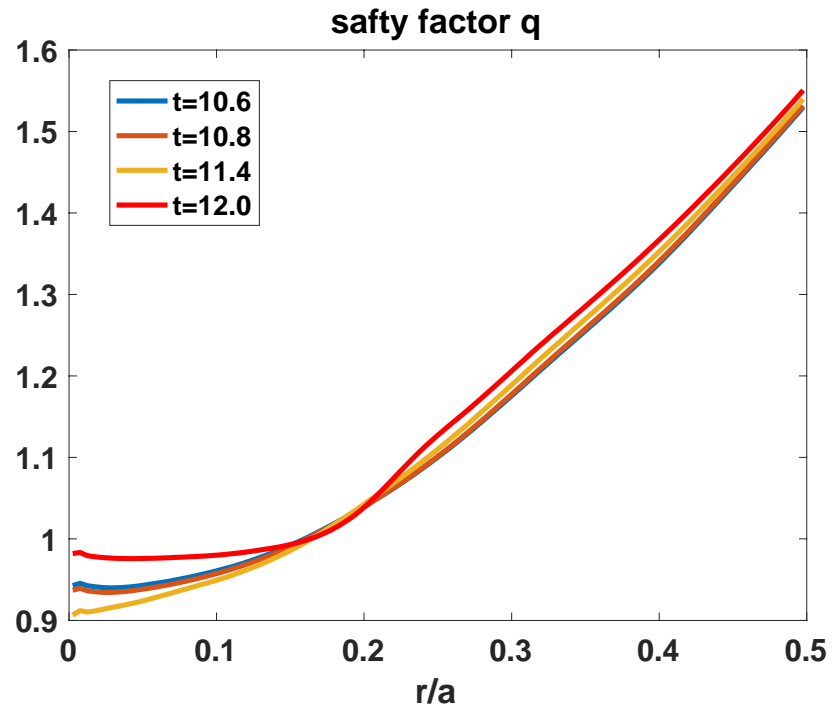
## Runaway current during 2<sup>nd</sup> ST phase



- At 2<sup>nd</sup> ST phase there is a  $n \sim 5$  mode reduced to  $n \sim 1$  mode in runaway current
- The instabilities in runaway current may cause the much lower kinetic energy at 2<sup>nd</sup> ST phase.



## q profile during 2<sup>nd</sup> phase



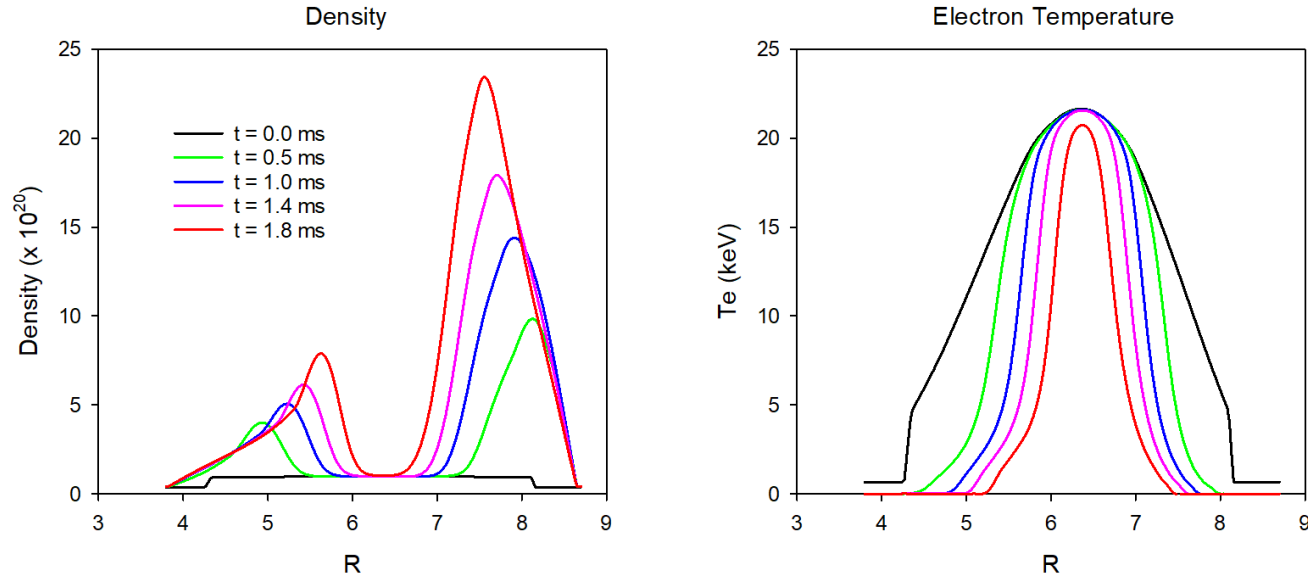
Directory : /projects/M3DC1/chenzhao/Chen2D-mod3/

## 2D ITER modeling of SPI -- Brendan Lyons 5/6/21

- I've recently started some 2D ITER modeling of SPI and I'm getting a weird result.
- The attached video show the density, every time step, from `/scratch/gpfs/bclyons/C1_11735` on stellar.
- Good NEWS
  - I got this to run to 2 ms by setting `pedge=.01`, `idenmfunc=1`
- Bad NEWS
  - After that time, code crashes with segmentation fault in velocity solve
  - Doesn't always crash at same time step, and numbers can be different for different runs restarting from same time!!

`/scratch/gpfs/sjardin/Brendan`

## 2D ITER SPI Modeling (cont)



- Density and temperature at  $Z = 1$  m at different times
- However, calculation stops with “segmentation fault” at seemingly random time steps...also, differing results!

# Inconsistencies in 2D nonlinear restarting at N=1000

## -1 slurm18347 died 1018 SEGV (SuperLU)

1000	2.7500E+03	3.0076E-01	3.6364E-01	2.8914E-02	2.7081E-01	1.0371E-03	6.3888E+02	2.1293E+04	3.2050E+02	2.22524E+04
1001	2.7528E+03	3.0125E-01	2.9180E-04	2.9007E-02	2.7121E-01	1.0298E-03	6.3882E+02	2.1293E+04	3.2028E+02	2.22521E+04
1002	2.7555E+03	3.0170E-01	2.7516E-04	2.9101E-02	2.7157E-01	1.0278E-03	6.3875E+02	2.1293E+04	3.2005E+02	2.22518E+04
1003	2.7582E+03	3.0214E-01	2.6496E-04	2.9189E-02	2.7193E-01	1.0246E-03	6.3869E+02	2.1293E+04	3.1982E+02	2.22515E+04

## -2 slurm18516 died 1088 SEGV (SuperLU)

1000	2.7500E+03	3.0076E-01	3.6364E-01	2.8914E-02	2.7081E-01	1.0371E-03	6.3888E+02	2.1293E+04	3.2050E+02	2.22524E+04
1001	2.7528E+03	3.0124E-01	2.8901E-04	2.9007E-02	2.7120E-01	1.0298E-03	6.3882E+02	2.1293E+04	3.2028E+02	2.22521E+04
1002	2.7555E+03	3.0169E-01	2.7320E-04	2.9100E-02	2.7157E-01	1.0279E-03	6.3875E+02	2.1293E+04	3.2005E+02	2.22518E+04
1003	2.7582E+03	3.0214E-01	2.6685E-04	2.9188E-02	2.7192E-01	1.0250E-03	6.3869E+02	2.1293E+04	3.1982E+02	2.22515E+04

## -3 slurm18607 died 1049 SEGV (SuperLU)

1000	2.7500E+03	3.0076E-01	3.6364E-01	2.8914E-02	2.7081E-01	1.0371E-03	6.3888E+02	2.1293E+04	3.2050E+02	2.22524E+04
1001	2.7528E+03	3.0124E-01	2.9042E-04	2.9007E-02	2.7121E-01	1.0298E-03	6.3882E+02	2.1293E+04	3.2028E+02	2.22521E+04
1002	2.7555E+03	3.0170E-01	2.7414E-04	2.9101E-02	2.7157E-01	1.0278E-03	6.3875E+02	2.1293E+04	3.2005E+02	2.22518E+04
1003	2.7582E+03	3.0214E-01	2.6593E-04	2.9189E-02	2.7193E-01	1.0248E-03	6.3869E+02	2.1293E+04	3.1982E+02	2.22515E+04

Each of these died in the velocity solve with a segmentation fault at different time steps!



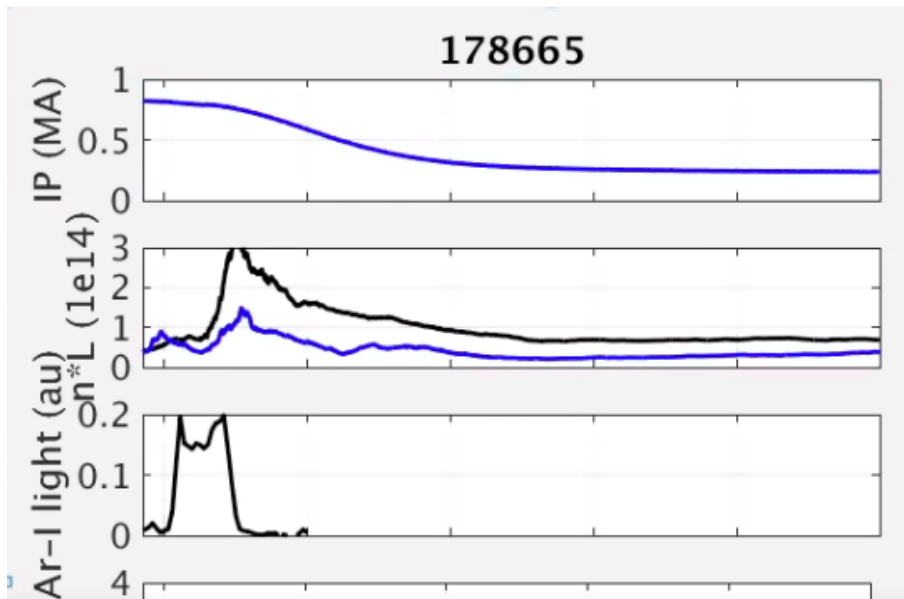
## 5/31/21 meeting w JOEREK regarding RE benchmark

\* A recent paper has appeared using the 1 ½ D code ASTRA-STRAHL to examine in detail a ASDEX-U mitigation shot that produced Runaway Electrons. Linder, et al. “Self-consistent modeling of runaway electron generation in massive gas injection scenarios in AUG”, NF 60 (2020) 096031

- 1) Vinodh and Matthias will look further into defining the setup for the AUG based benchmark case that was looked at with ASTRA-STRAHL and contact the M3D-C1 team as soon as they have something ready.
- 2) Chen will look into modeling the DIII-D discharge 178665 and will let JOEREK team know when there are any interesting observations.
- 3) The two teams will meet again in a few weeks as soon as there is something new to look at for 1) or 2).

In attendance: Matthias Hoelzl, Vinodh Bandaru, Chen Zhao, Stephen Jardin

# DIII-D RE generation with Ar shot 178665



Carlos suggested this shot:

$\langle n_e \rangle$ ,  $Te(r,t)$ ,  $IP(t)$ , AR-1 ( $R,Z,t$ )

Eric Hollman studied this shot in detail in an upcoming paper so we may want to write to him

Use equilibria from 177053. You might want to look at matching the pre-TQ density integral to 665

That's All I have

Anything Else ?

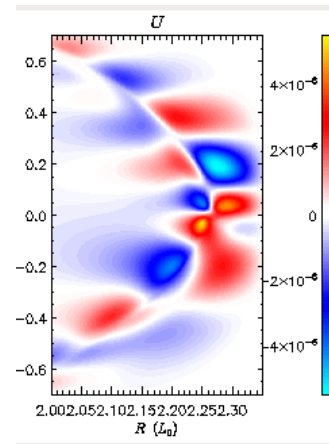
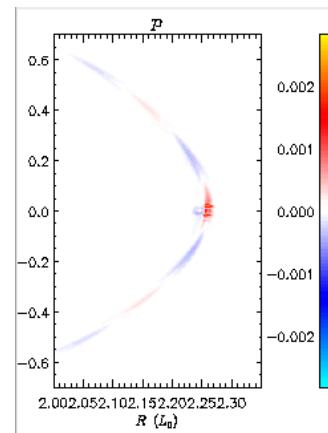
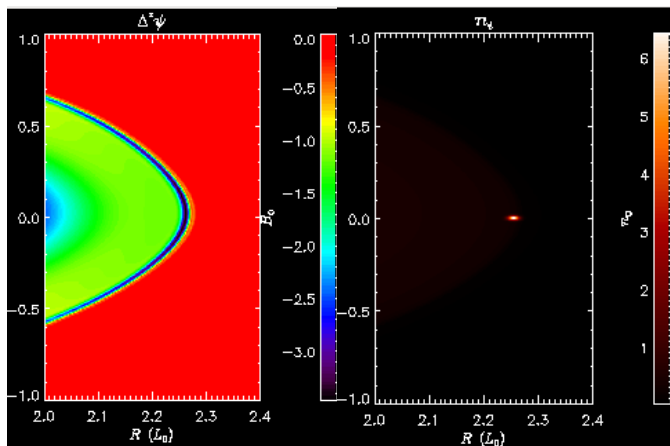
That's All I have

Anything Else ?

# M3D-C1 modeling of pellet ELM triggering in low-collisionality discharges

- Preprint by A. Wingen (ORNL), Linear and non-linear simulations
- Linear simulation with  $i_{\text{pellet}}=1$  perturbs only the density profile. Large enough perturbation excites an unstable mode

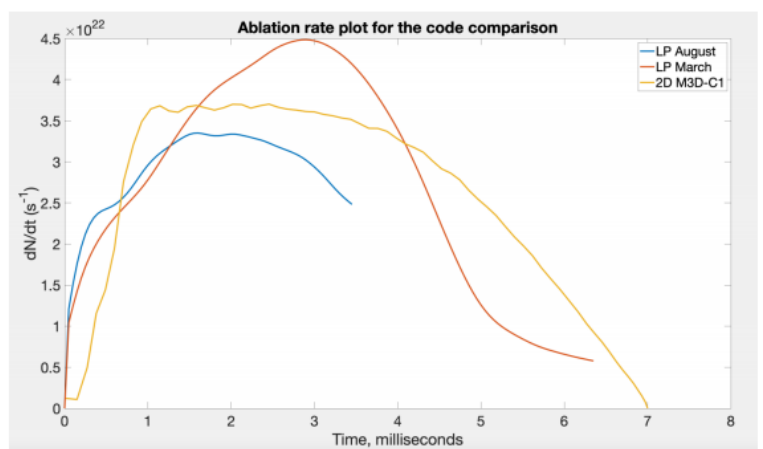
**Q: How does a density perturbation excite a MHD mode?**



Density perturbation causes decreased  $T_e$  at one location on flux surface. Thermal conduction during linear phase causes pressure to increase there. Gives an unstable mode for  $n_{\text{tor}}=9$  only if  $k_{\text{app}} \neq 0$

# Interfacing M3D-C1 and LPC

- Zoom meeting was held 04/08/21 with Roman Samulyak and students
- Presentation posted on [m3dc1.pppl.gov](http://m3dc1.pppl.gov)
- Small differences between m3dc1 pellet model and LPC local model
- Brendan to see what data is available for single neon pellet ablation test
- **Daisuke Shiraki will address this in a special call set for Tuesday at 2:00 ET. Lyons, Samulyak, Jardin, ..... (assuming Samulyak availability)**



## Approach to nonlinear MHD simulations in stellarator geometry

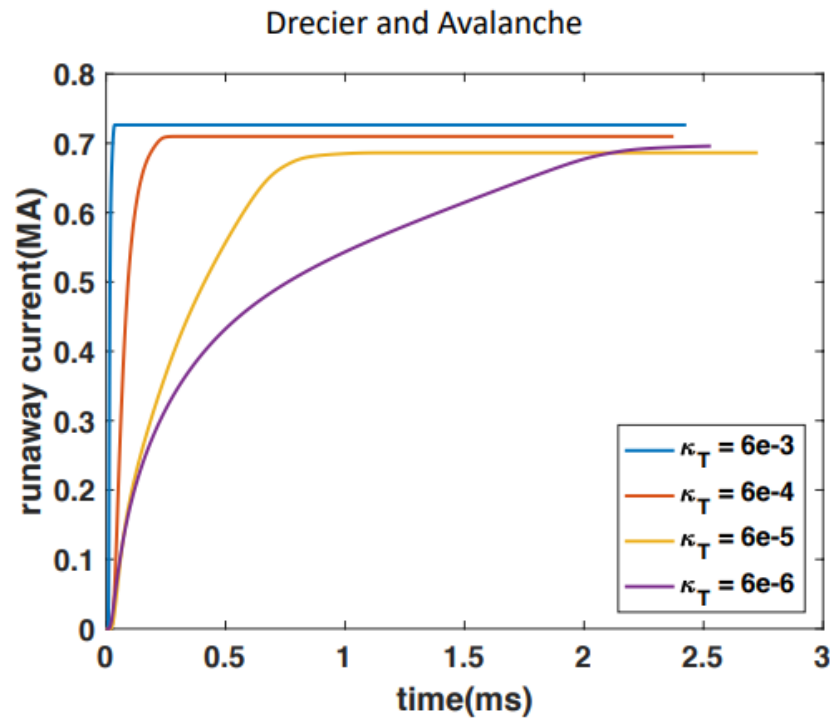
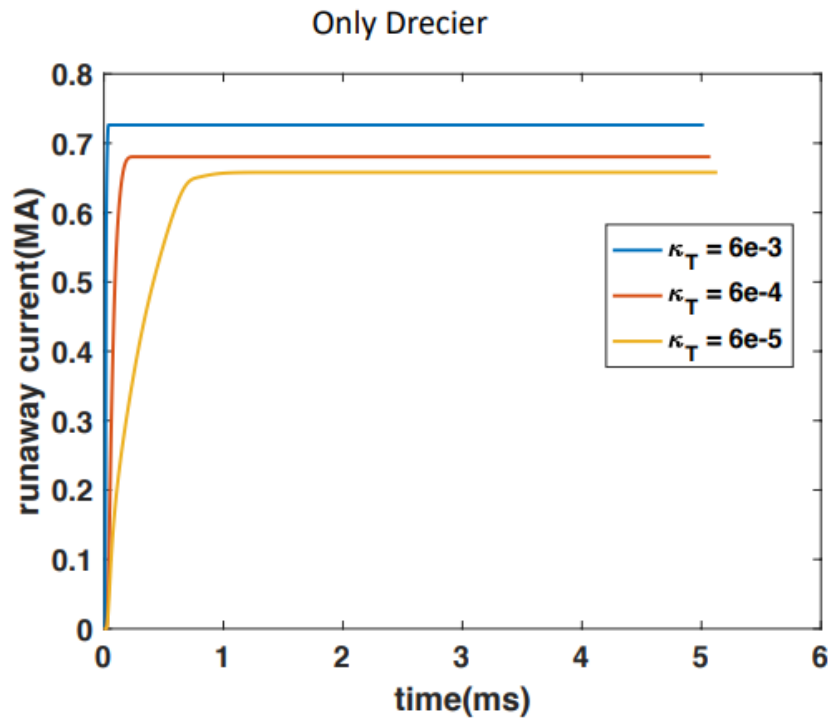
- Yao Zhou has an excellent preprint he plans to submit to Nuclear Fusion

# Self-consistent simulation of resistive kink instabilities with runaway electrons

- Chang Liu, et al manuscript submitted to Plasma Physics and Controlled Fusion 04/21/2021



# Effect of Avalanche term on DIII-D 177053



## Next Steps

- Chen Zhao should consider writing a paper on the incorporation of the runaway source term in M3D-C1 and include the DIII-D result
- NIMROD is interested in doing a benchmark of the runaway source calculations. I gave them Chen's equilibrium and results. This could be included in paper if done sufficiently fast.
- I asked Carlos Paz-Soldan to help us identify a series of DIII-D shots where runaways are generated and there are good diagnostics. Still waiting to hear. (he did indicate that he's working on it)
- We had a zoom call with the JOREK group this morning. They will also check with ASDEX-U to see if there is a series of experiments that we could model

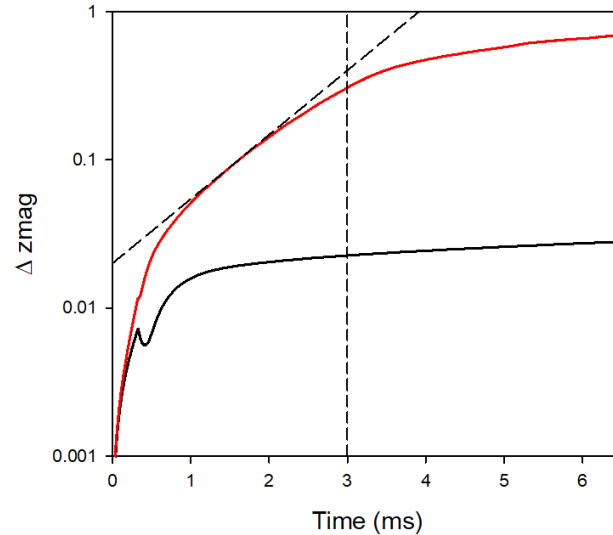
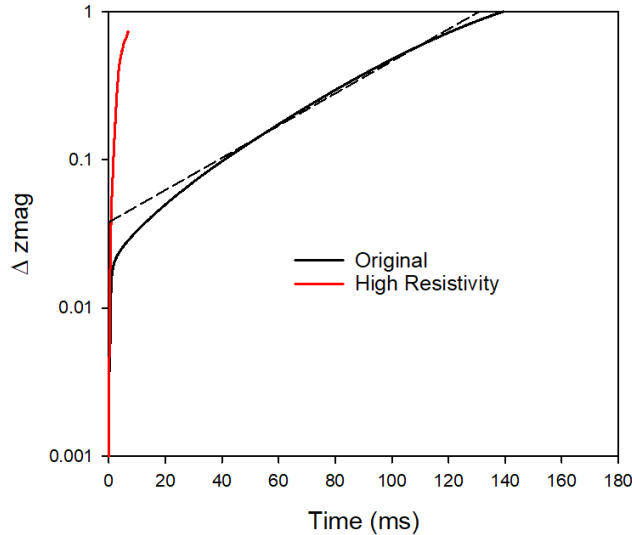
# Effect of resistive wall on the thermal quench

- Hank Strauss requested an EFIT equilibrium for shot 154576 at 3312ms, just before it disrupts
- This was studied in the paper: R. Sweeney, et al, "Relationship between locked modes and thermal quenches in DIII-D"
- Focus of paper is that sometimes overlapping locked modes just flatten the temperature around the  $q=2$  surface ( $q=3/2$  to edge) whereas sometimes they also cause a collapse of the core temperature
- NIMROD simulations were initialized with islands of the size and phase of the experiment:  $3/2$ ,  $2/1$ ,  $3/1$ , and  $4/1$
- In the simulation, the  $2/1$  island decays in time, unlike in the experiment. Also, the experiment shows a wider region of  $T_e$  collapse. Can M3DC1 improve on this?

# Current coupling scheme of fishbone simulation in M3D-C1

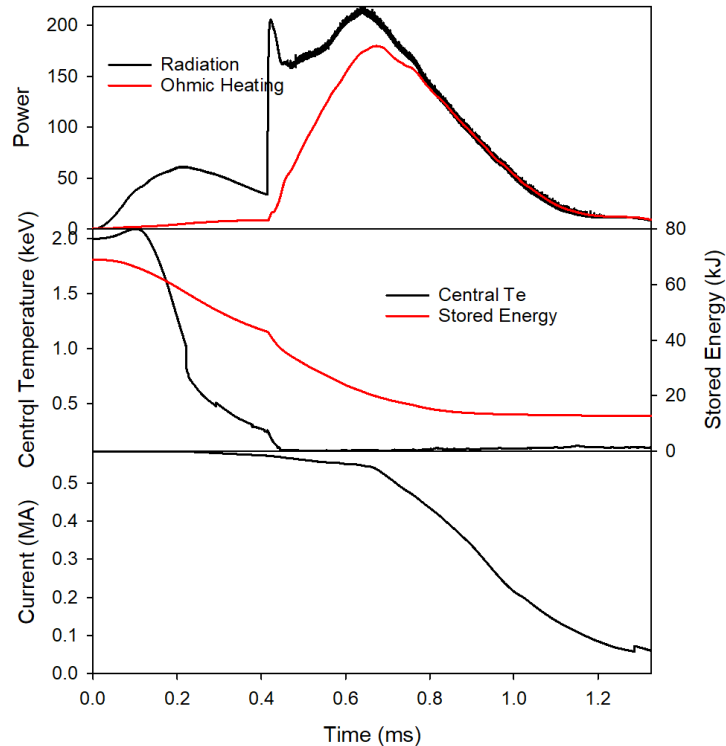
- Chang Liu to present

# ITER disruption with more resistive vessel



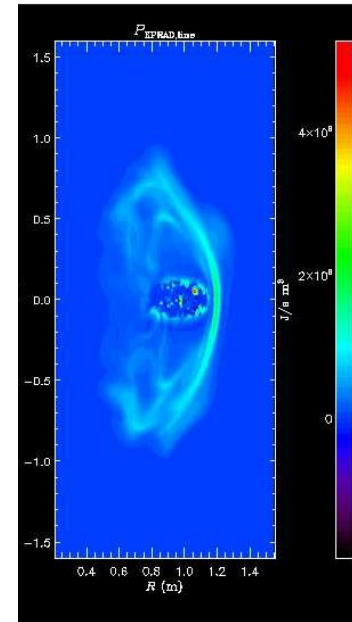
- Increased all vessel resistivities by 100
- Growth rate went from  $.025 \text{ ms}^{-1}$  to  $2.0 \text{ ms}^{-1}$
- New case greatly slows down after contact with wall is made

# Carbon Mitigation in NSTX-U (shell pellet)



Shell carbon pellet in NSTX (now running)

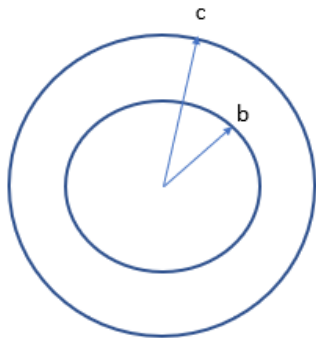
Radiation  
 $t = 0.73$  ms



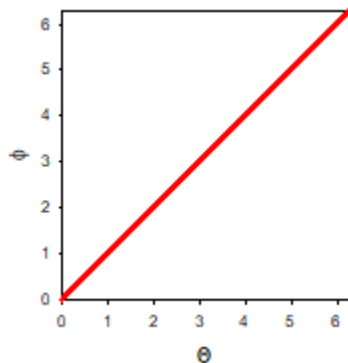
This run is essentially done and can be incorporated into Cesar's paper

# Helical Band to remove runaway electrons

- Brendan Lyons performed a calculation last year with a conducting helical band that did not show large helical currents
- Want to try and reproduce, first in circular cylindrical geometry.



Circular cylindrical geometry.  
Conductor in region  $b < r < c$



3D helical band of good conductivity at  $|\Theta - \phi| < \delta$

#1. Will a purely toroidal voltage from the plasma current decaying drive a helical current in this geometry?

$$\nabla \times \mathbf{E} = 0 \Rightarrow \mathbf{E} = -\nabla \Phi + \frac{V_L}{2\pi} \nabla \phi$$

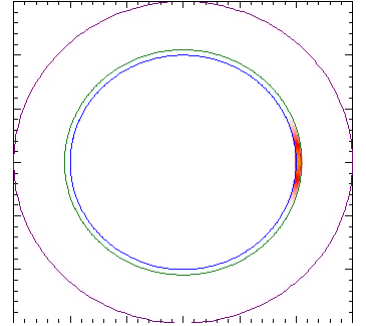
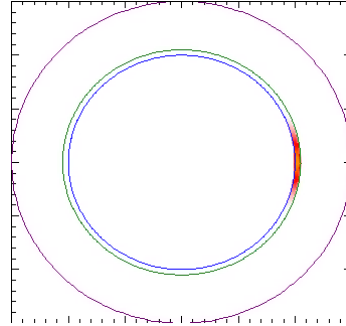
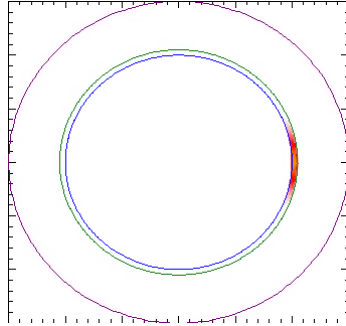
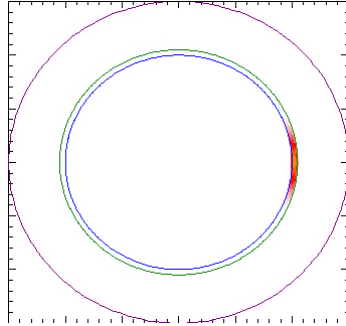
$$\mathbf{J} = \sigma \mathbf{E}$$

What is driving the current in the  $\theta$  direction? It can't be  $\Phi$  unless

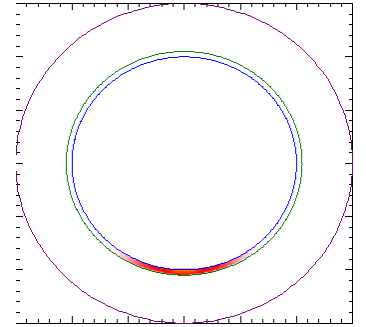
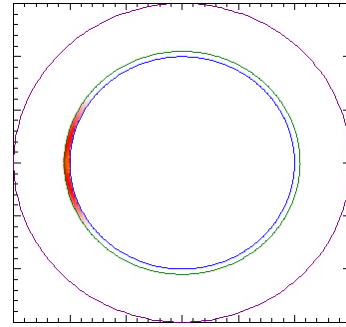
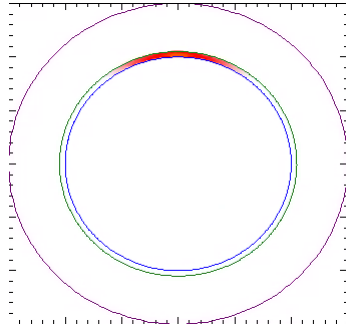
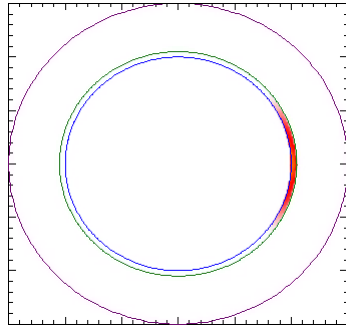
$$\int_0^{2\pi} \sigma^{-1} J_\theta d\theta = \int_0^{2\pi} \frac{d\Phi}{d\theta} d\theta = 0$$

# Comparison between Straight and helical band

Straight →



Helical →



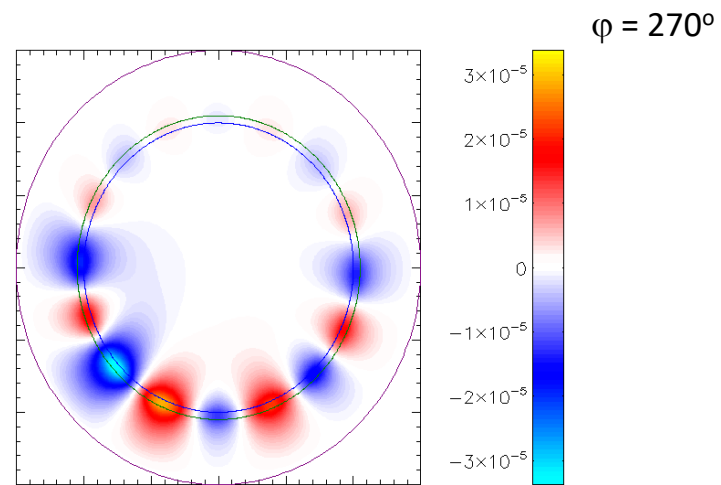
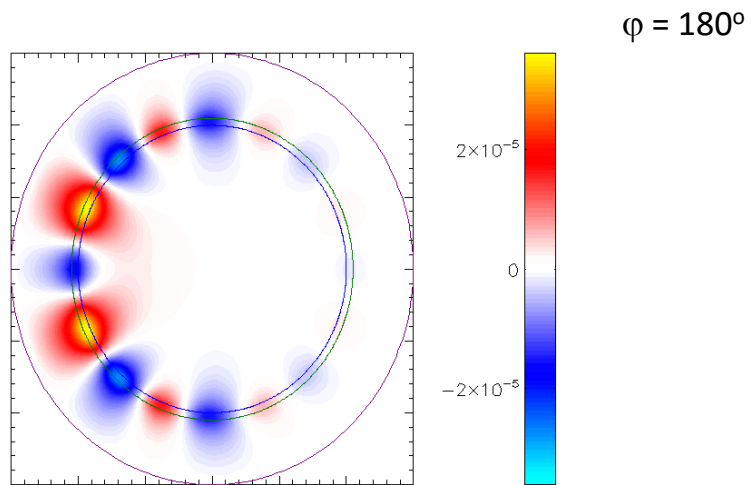
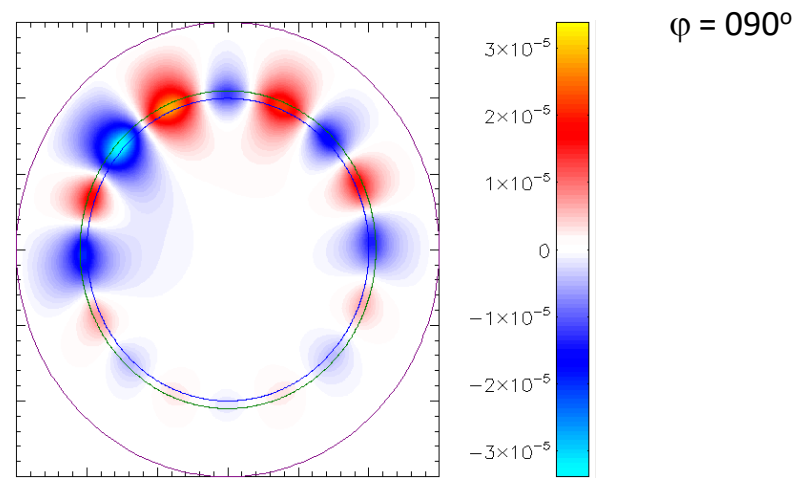
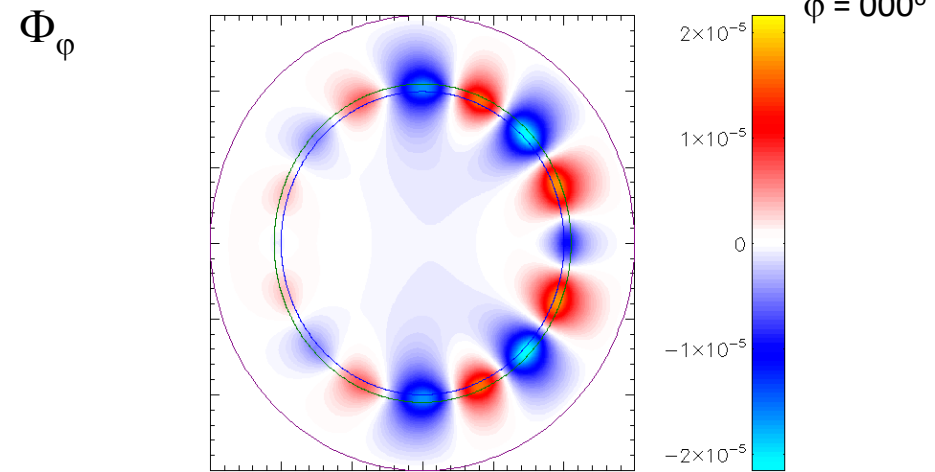
$$\varphi = 0$$

$$\varphi = \pi / 2$$

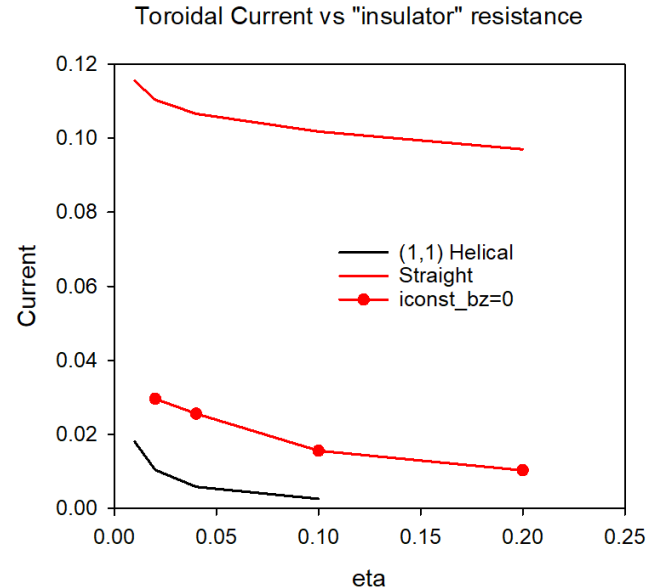
$$\varphi = \pi$$

$$\varphi = 3\pi / 2$$



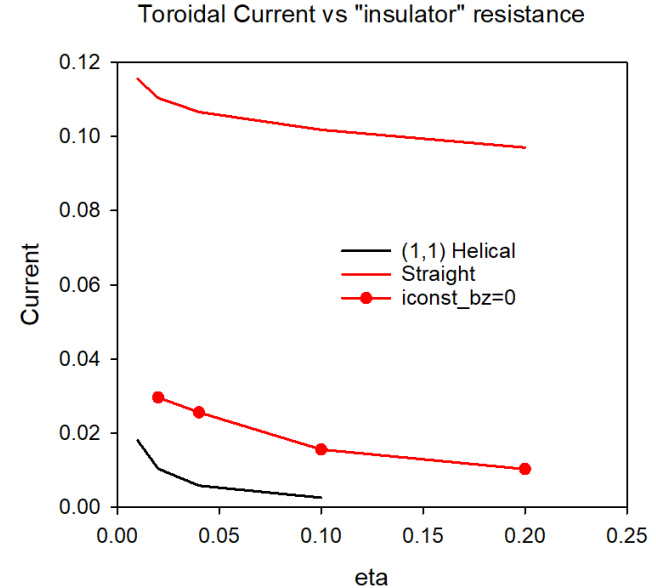
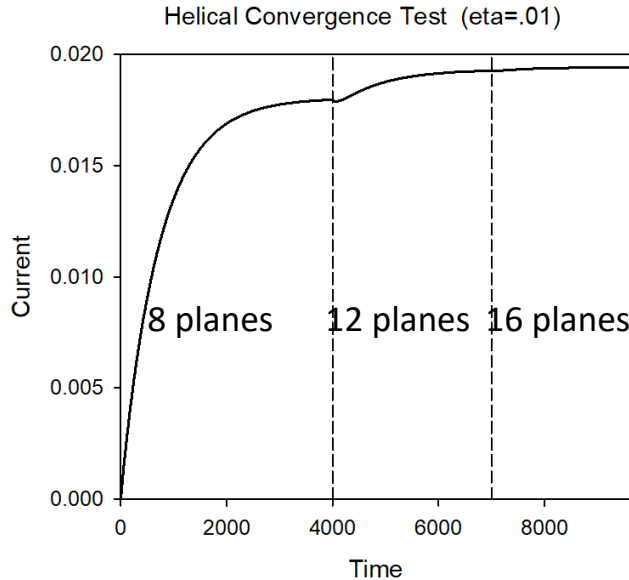


# Helical resistive band to suppress runaways



- I have asked Matthias Hoelzl if he could try and reproduce this with the STARWALL code. He seems interested

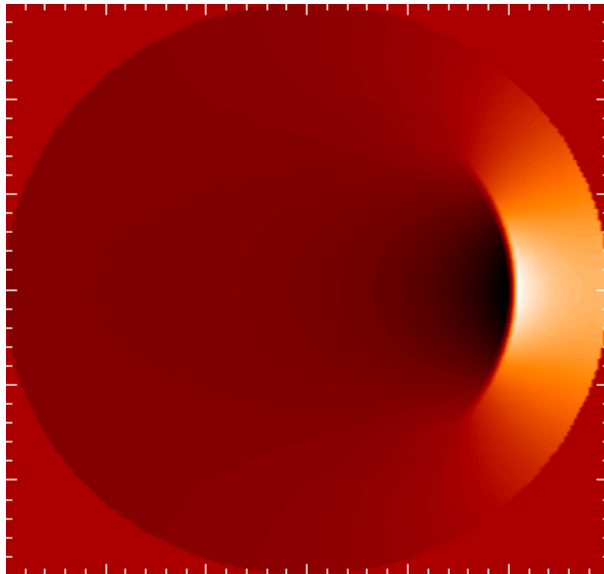
# Some Convergence Tests



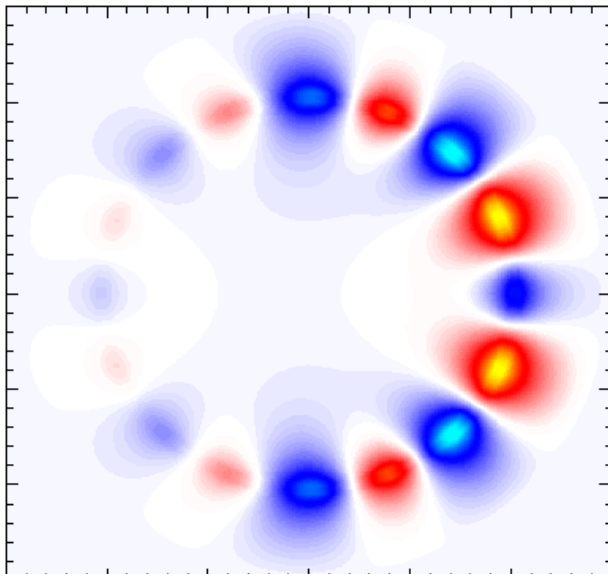
- Wall current appears to be converged in # of planes
- Helical wall current tending towards zero for large values of insulator resistance
- Now testing dependence on boundary conditions (location of ideal wall)
- Helical (1,2) case gives less than half the current of helical (1,1) case
- Iconst\_bz=0 increases current, but still far below straight case

## Plots for iconst\_bz=0

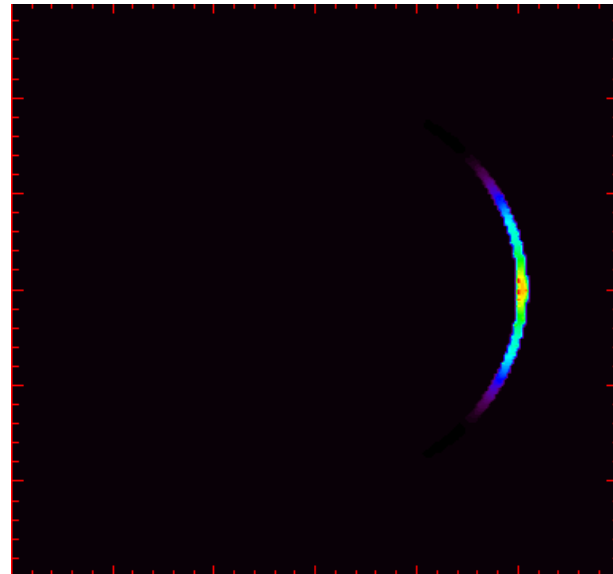
$I$



$\frac{\partial \Phi}{\partial \varphi}$



$J_\varphi$

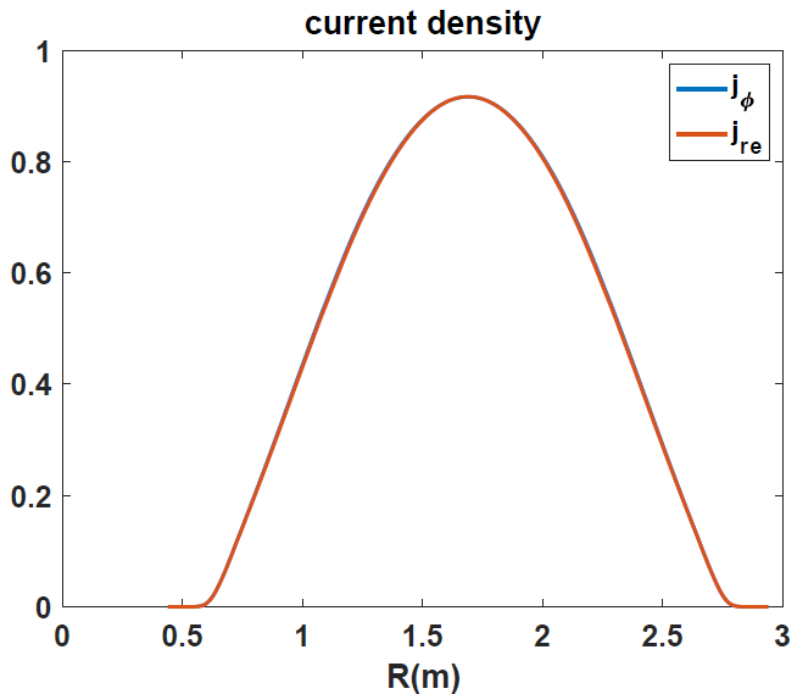
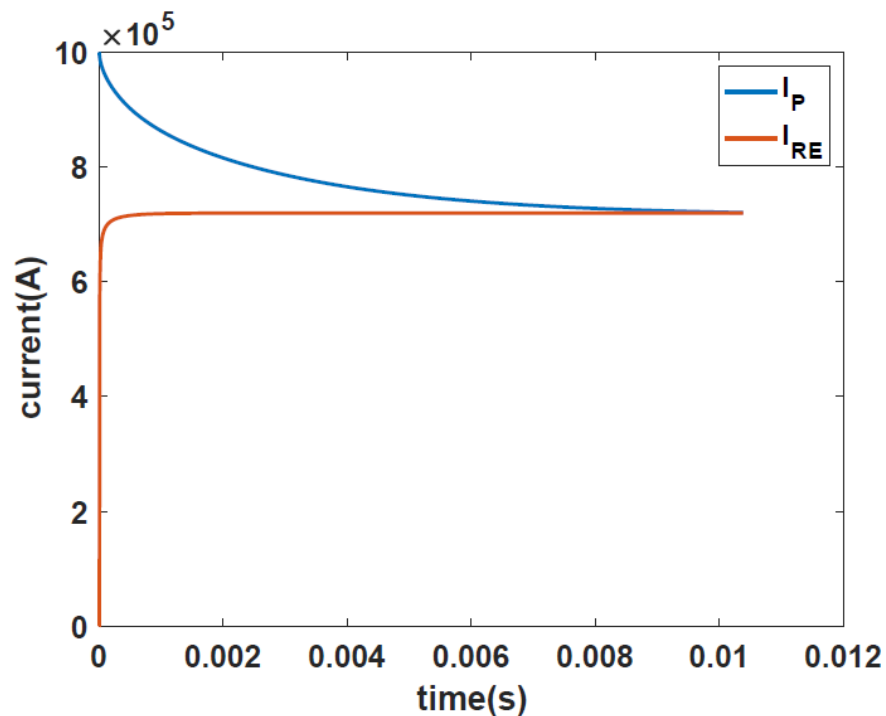


$$\nabla_\perp \cdot \frac{1}{R^2} \nabla \Phi = \nabla_\perp \cdot \eta \left[ -\frac{1}{R^2} \nabla F \times \nabla \varphi - \frac{1}{R^2} \nabla f'' \times \nabla \varphi - \frac{1}{R^4} \nabla_\perp \psi' \right]$$

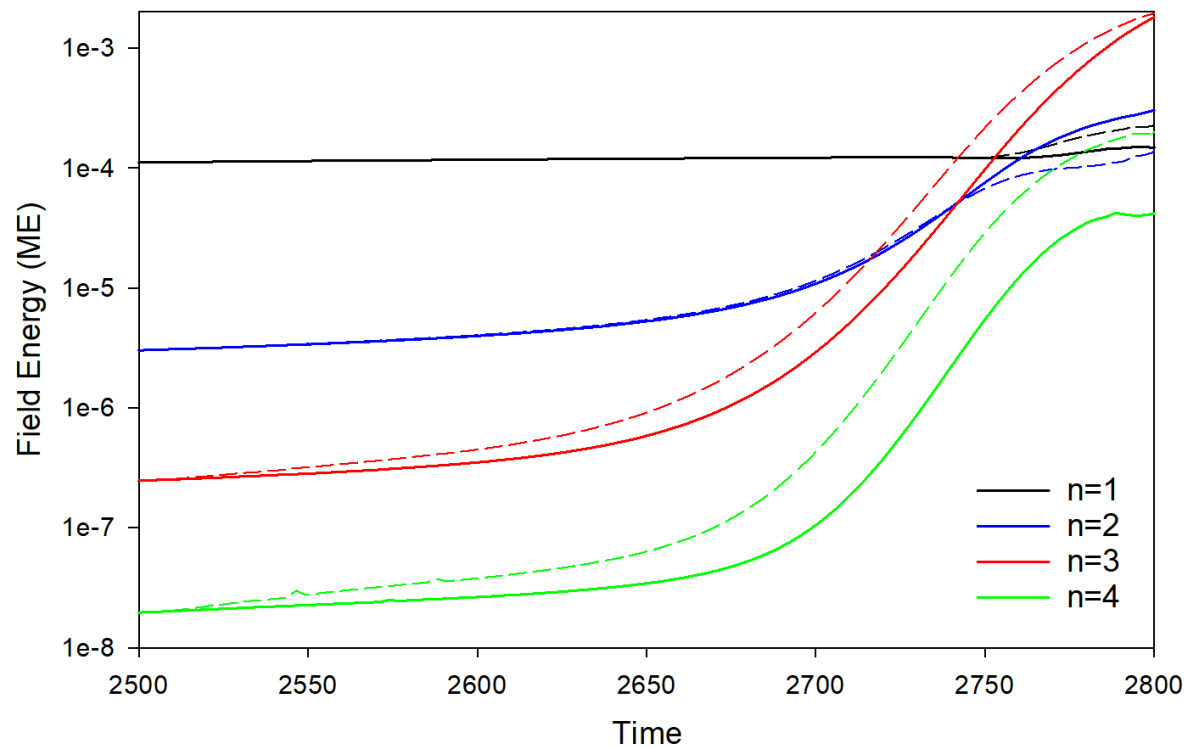
## Local Systems

- PPPL centos7(02/22/21)
  - 6 regression tests PASSED on centos7:
- PPPL greene (02/15/21)
  - 4 regression tests PASSED
  - RMP\_nonlin timed out (but gave correct results)
  - No batch file found for pellet
- EDDY (2/15/21)
  - 6 regression tests PASSED
- TRAVERSE(1/4/21)
  - Code compiles
  - Regression test failed: split\_smb not found in PATH
  - Have not yet tried shipping .smb files from another machine

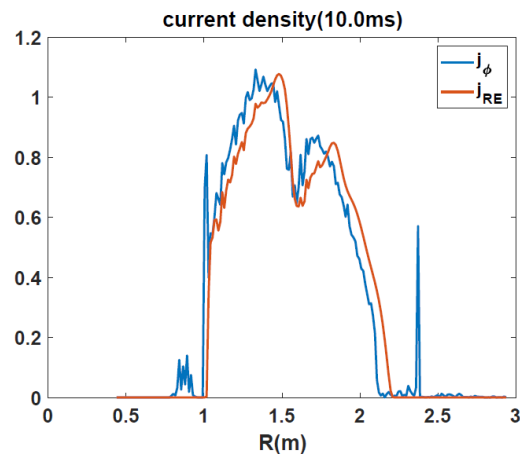
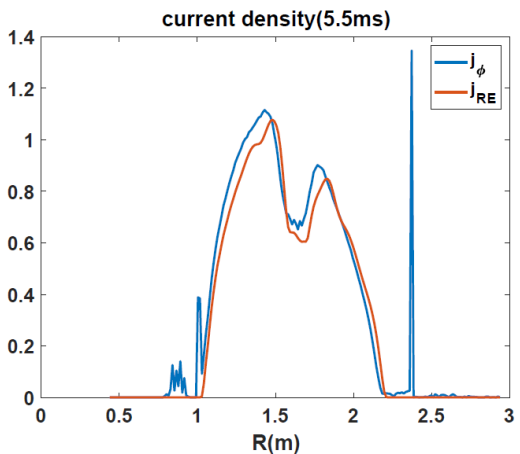
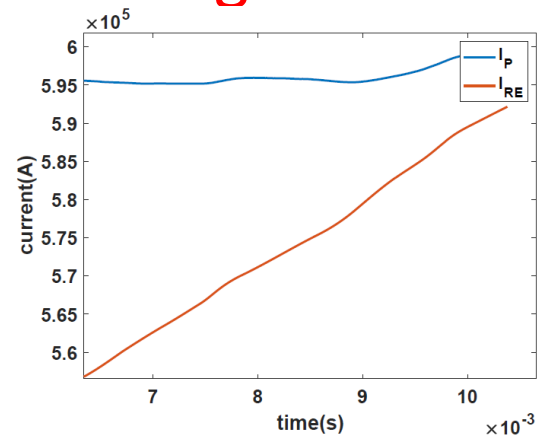
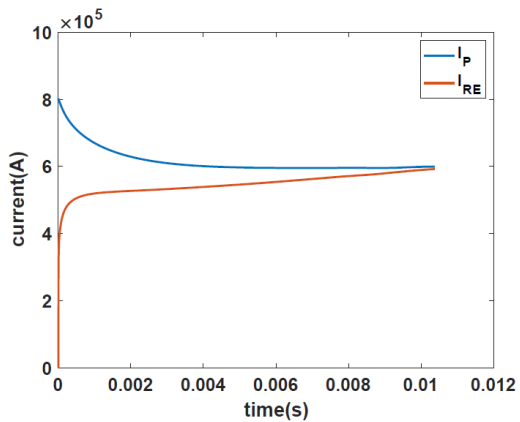
## 2D (cylindrical) RE with sources (12/19/2020)



## Energy in base case 36742317 (solid) and 16 plane case 37248033 (dashed)



# DIII-D 177053 with Argon

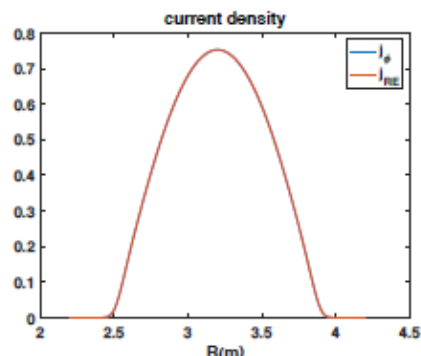
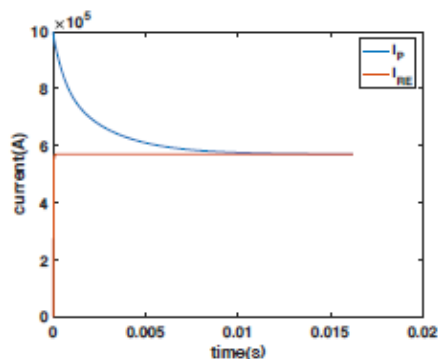


Chen Zhao



## Same calculation in a Cylinder

### M3D-C1 runaway generation with cylinder geometry



- Parameters:
$$\beta_0 = 0.15$$
$$a = 0.65m$$
$$R = 1.7m$$
$$B_0 = 1.9T$$
$$\eta = 1.0 \times 10^{-4}$$
$$n_0 = 1.0 \times 10^{20} m^{-3}$$
$$c = 150v_A$$
$$N_{elements} = 12261$$
$$\Delta t = 1.0\tau_A$$

- The plasma current was equal with plasma current by the runaway current at about 12ms.
- The radial profile of runaway current profile are exactly same when the plasma current equal to runaway current.

# Progress on other shots?

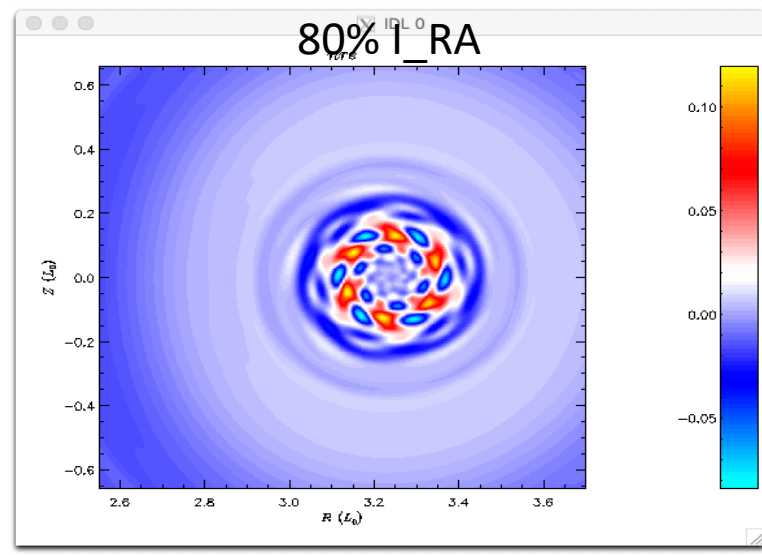
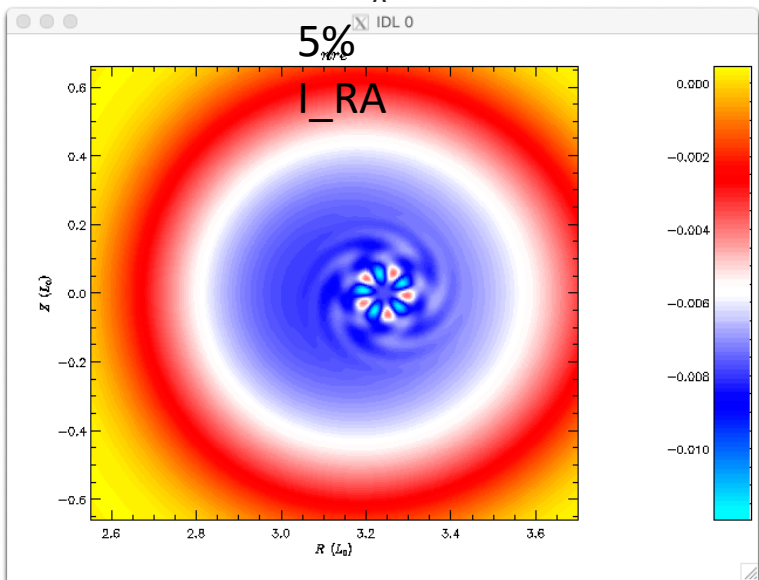
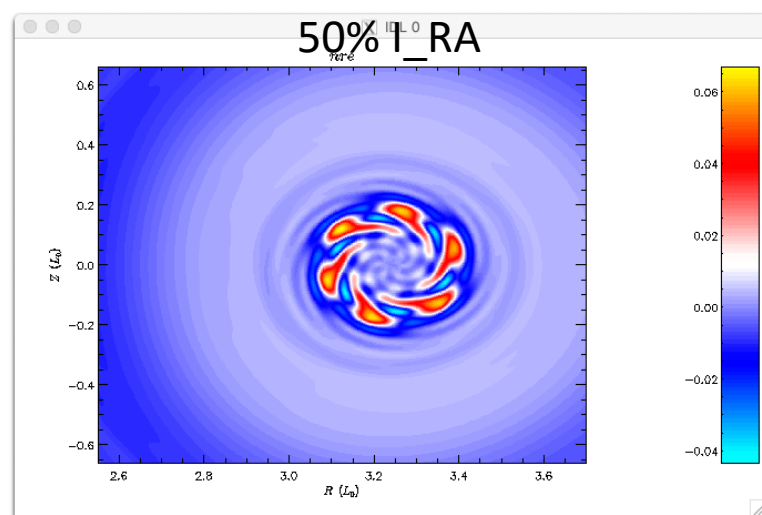
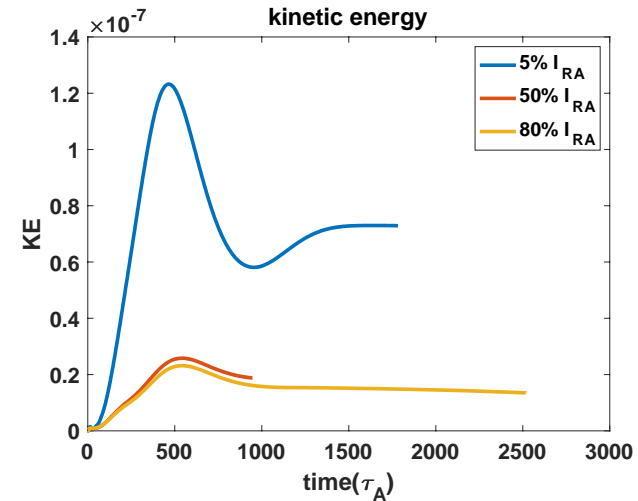
- M3D-C1/NIMROD 3D Benchmark

NSTX shot 1224020 – Fast ion transport with coupled kink and tearing modes  
Chang Liu

DIII-D Neon pellet mitigation simulation for KORC

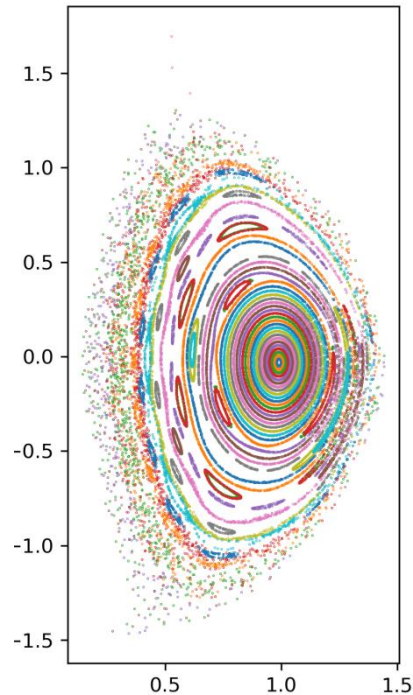
- Brendan Lyons trying to extend 8 plane case to 32 planes

SPARK ? Do we need to do anything?



## NSTX shot 1224020 – Fast ion transport with coupled kink and tearing modes

### Chang Liu

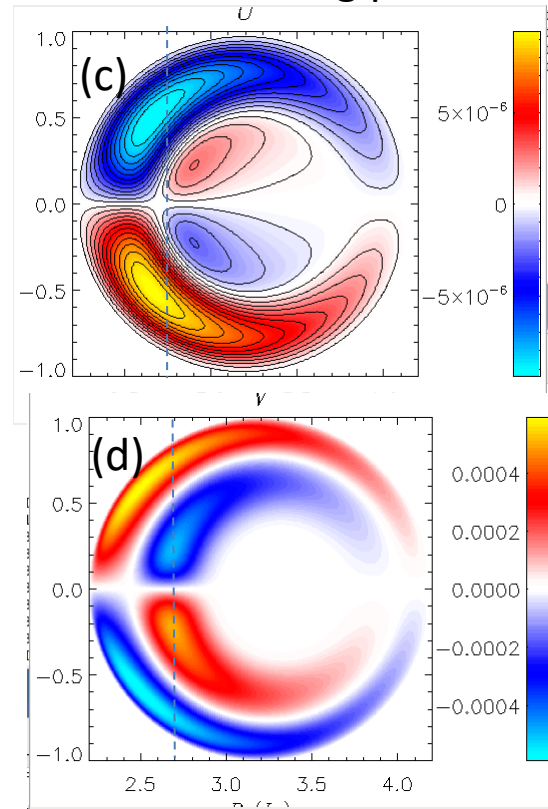
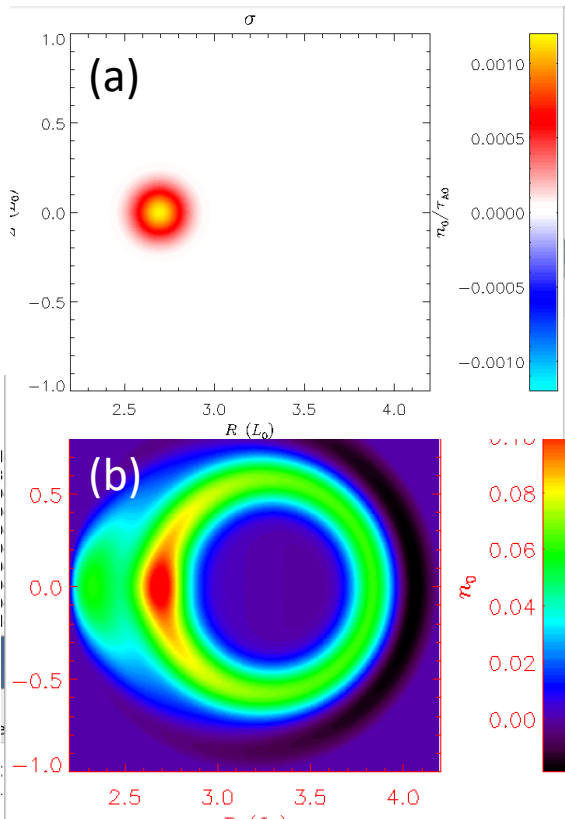


- In the original geqdsk file, the equilibrium was poorly converged. New one is much better. Has  $q(0) = 1.3$
  - Chang has analyzed new equilibrium (left)
  - No ideal (1,1) mode, several tearing modes
- 
- If goal is to get unstable (1,1) mode, likely need to lower  $q(0)$
  - Adding sheared toroidal rotation should help stabilize resistive modes.

# Grad-B drift in M3D-C1—HF side

Request to calculate grad-B drift in M3D-C1 and to compare with that being put into the LP Code

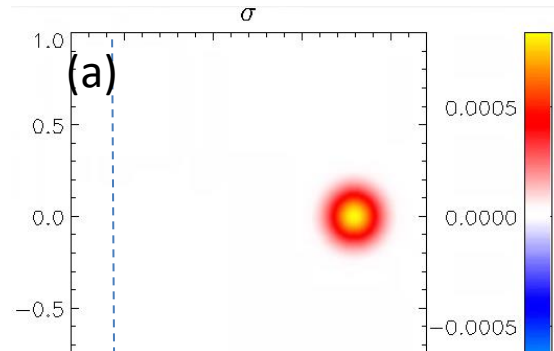
- (a) Density source in 1F toroidal equilibrium
- (b) Change in density after  $10^3 \tau_A$
- (c) Poloidal velocity stream function
- (d) Toroidal velocity contours



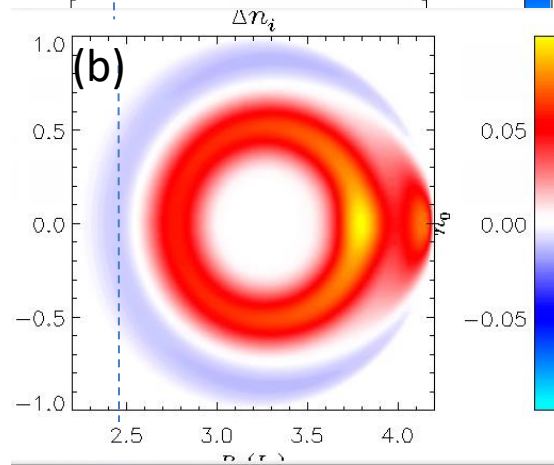
# Grad-B drift in M3D-C1– LF source

Request to calculate grad-B drift in M3D-C1 and to compare with that being put into the LP Code

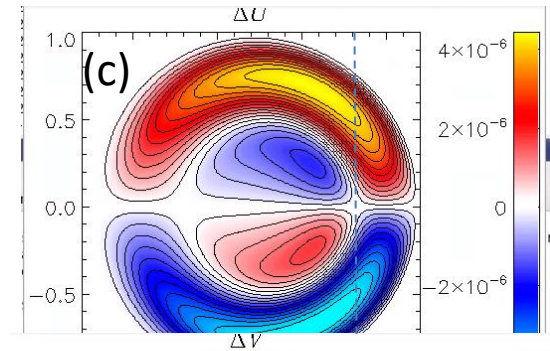
(a) Density source in 1F toroidal equilibrium



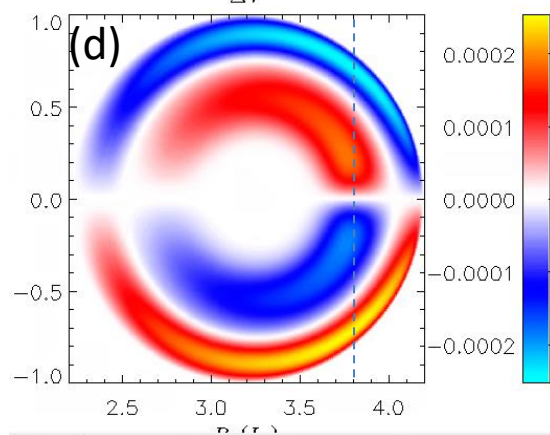
(b) Change in density after  $10^3 \tau_A$



(c) Poloidal velocity stream function

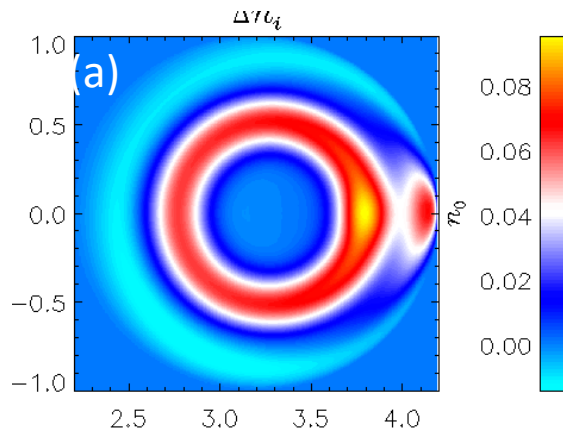


(d) Toroidal velocity contours

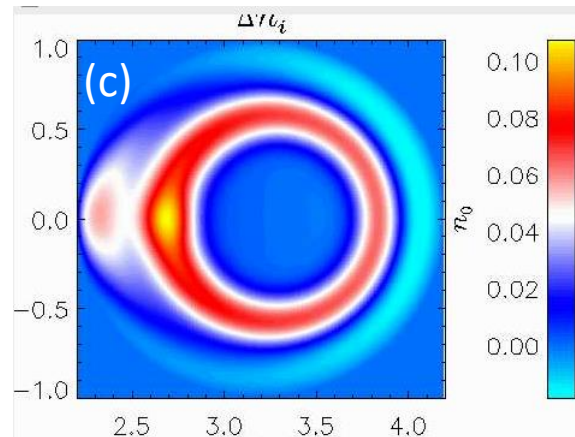


## Grad-B drift in M3D-C1—2F effects

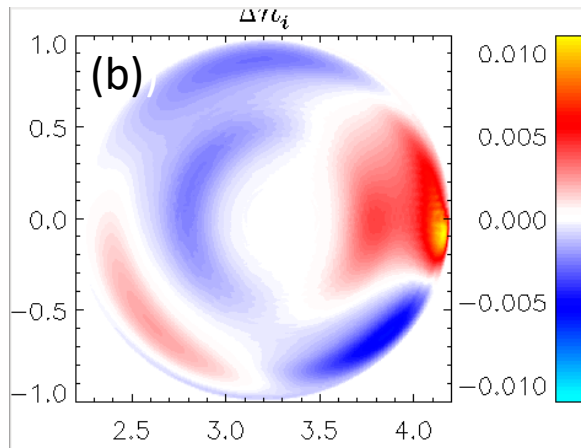
(a) 2F density change  
after  $10^3 \tau_A$  for LF  
side source



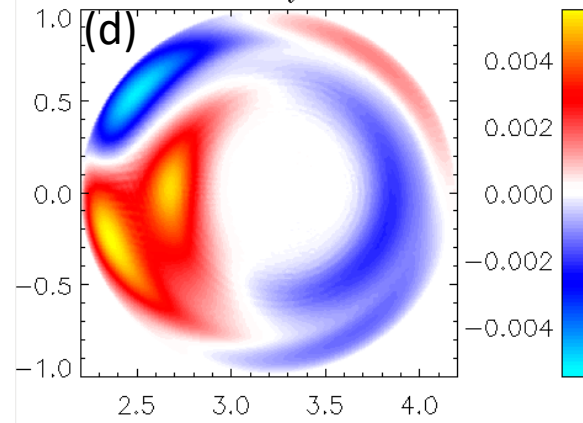
(b) Difference in 1F and  
2F density (LF)



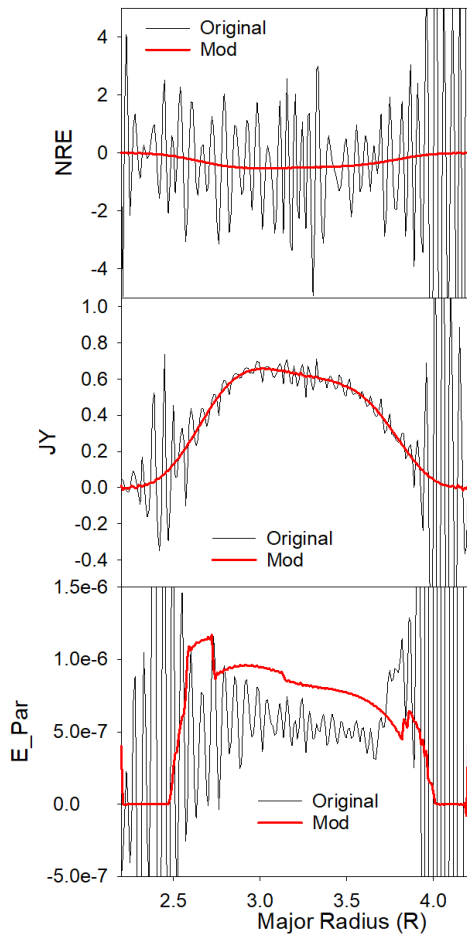
(c) 2F density change  
after  $10^3 \tau_A$  for HF  
side source



(d) Difference in 1F and  
2F density (HF)



# Sawtoothing discharge with runaway electrons



Profiles of nre, jy, and E\_par after 30 timesteps

Original: /p/tsc/m3dnl/Isabel/Chen2D

Mod: /p/tsc/m3dnl/Isabel/Chen2D-mod1

Changed:

**mesh size**

“regular”

**“integration points”**

ipres=1

cre

pedge

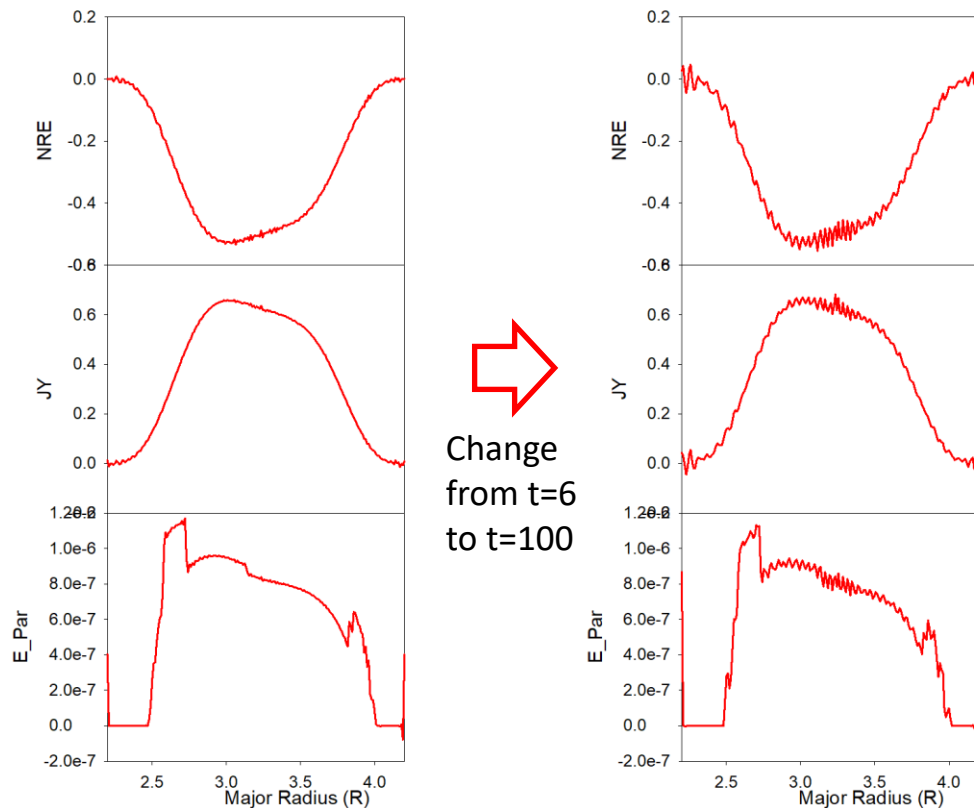
viscosity

denm

equilibrium density



# Longer times develops oscillations



- Short wavelength oscillations occur first in nre and then in other quantities (jy, e\_par)
- Could we add some smoothing?