Progress on JA-2 Benchmark on Tearing Mode Calculations

(Based on Hender's ITPA-MHD Report)

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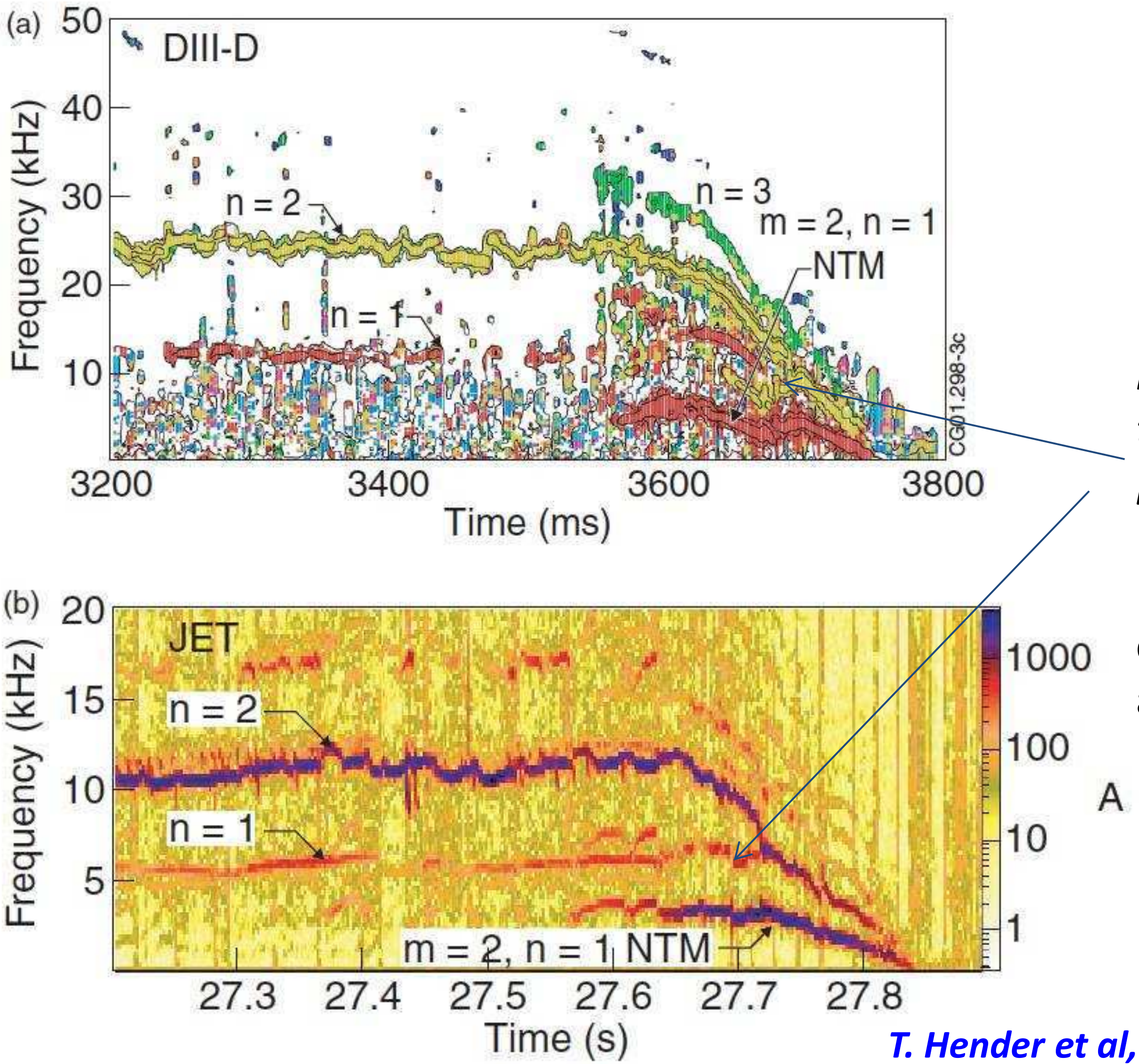
Goals and Participants of JA-2 of ITPA-MHD Topical Group

- Objective: *Study of coupled (neoclassical) tearing modes to gain fundamental understanding of their nonlinear dynamics including possible phase locking and disruptive phenomena and to explore the influence of plasma rotation on such nonlinear states.*
- Leader: T Hender
- Participants: D Chandra, N Ferraro, S Jardin, W -L Huang, R La Haye, E Lazzaro, J Mendonca, O Sauter, A Sen, A Thyagaraja, B Tobias, J -L Wang, Z -X Wang, and P Zhu (others welcome to join)

Experimental results - NTMs

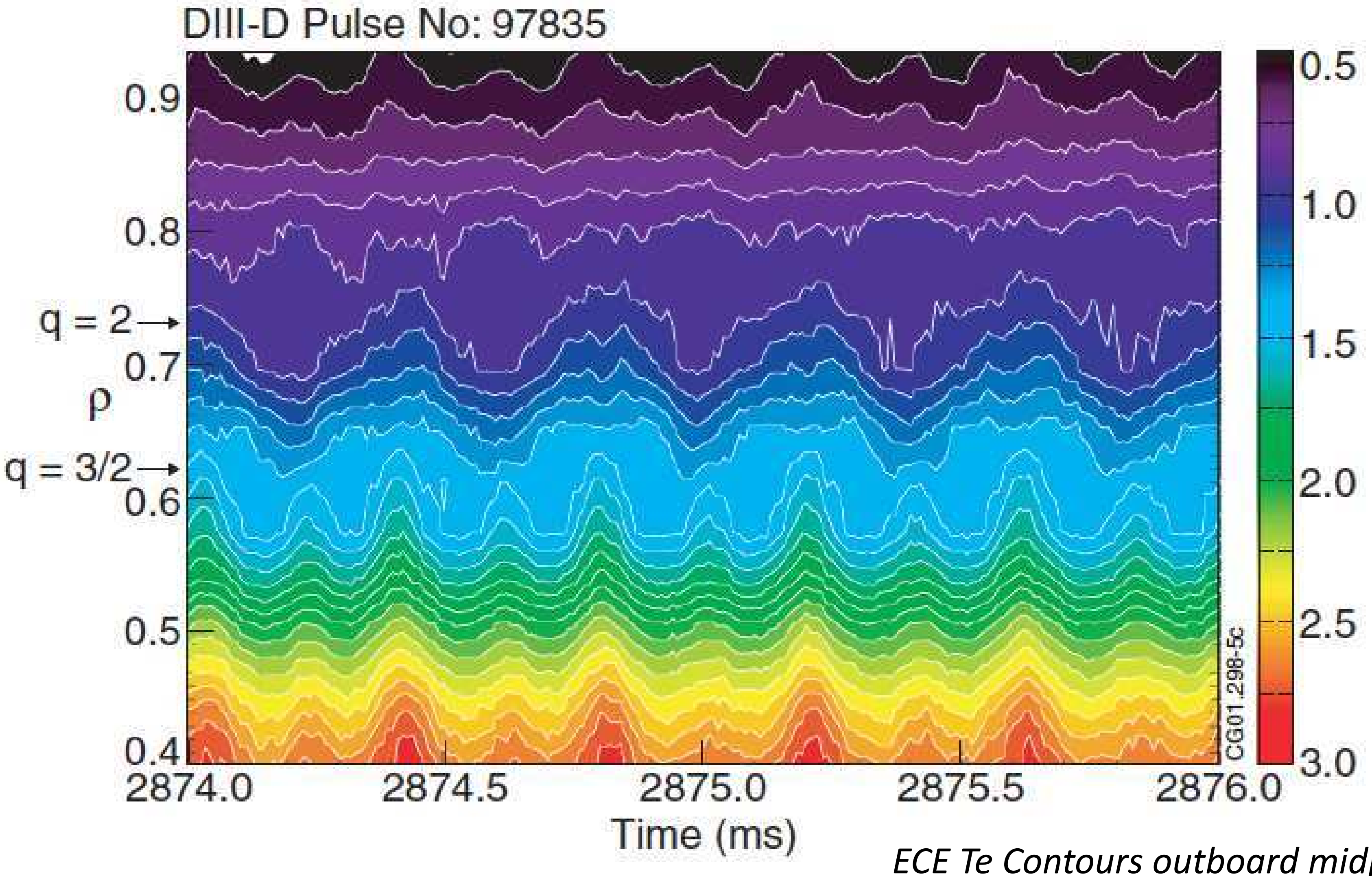


*n=2 phase locks to n=1; theory by R Fitzpatrick, [PoP **22**, 042514 (2015)]*

NB There are **no** sudden changes in mode amplitude when the modes phase lock

T. Hender et al, Nucl. Fusion 44 (2004) 788–794

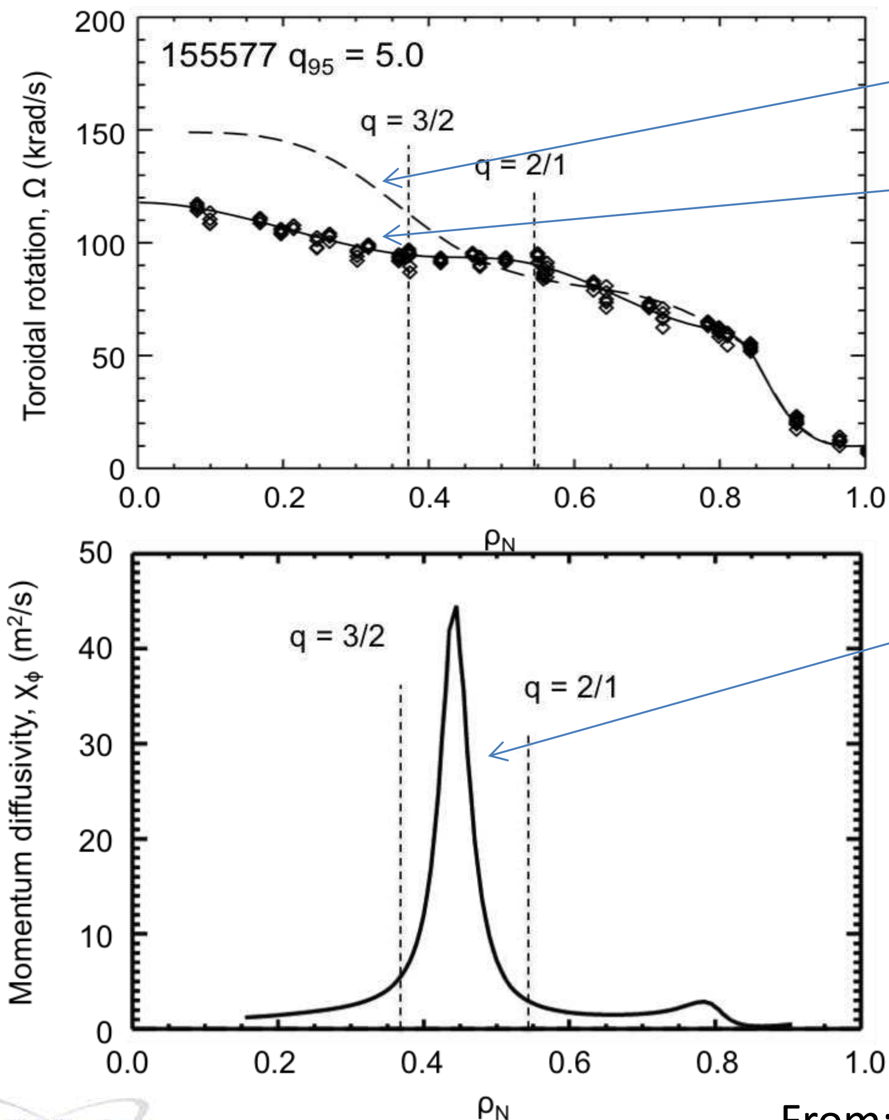
Experimental results - NTMs



ECE Te Contours outboard midplane

T. Hender et al, Nucl. Fusion 44 (2004) 788–794

Experimental results – phase locked NTMs



- The rotation profile changes are integral to understanding the mode stability and phase locking

- Since at q=2 χ_{mom} ~0, total angular momentum conserved for q<2, but redistributed between q=3/2 and 2.

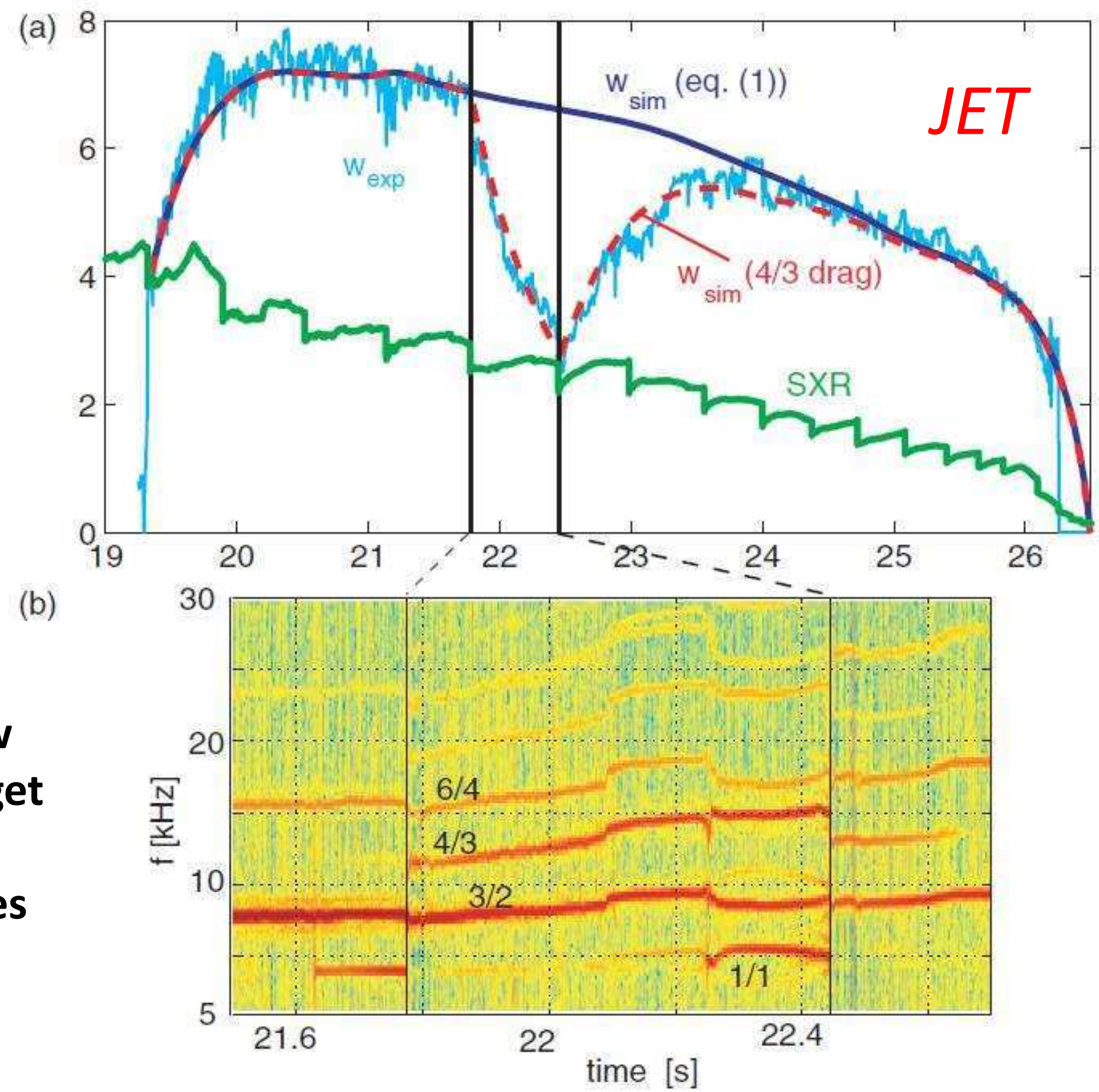
From: B Tobias , presented 2015 APS DPP

Interacting 4/3 and 3/2 NTMs

2 consecutive ST crashes trigger and stabilize 4/3

3/2 evolution consistent with a constant negative Δ' in modif. Ruth eq.

- **Yu et al, NF 40 (2000) 2031: Analytical/numerical study – show that when two magnetic islands get close to each other the more unstable one grows and suppresses the other**



O. Sauter, PPCF **44** (2002) 1999

Experiment - Summary

- NTMs of different helicity may or may not phase lock (bicoherence analysis is best way to confirm)
- Phase locking doesn’t produce a strong growth rate response
- Theory developed by R Fitzpatrick (toroidicity is key)
- Interacting modes cause local torques and momentum redistribution (probably the most important effect)
- NTMs interaction can be stabilising
- Effects are a combination of direct mode coupling and feedback through q and V_{ϕ} profile changes

Work plan

- Ultimate goal is study 2 nonlinearly interacting tearing modes in full toroidal geometry including flows
- Using M3D-C1 (PPPL), NEAR (IPR), NIMROD (USTC and UW-Madison) + (reduced MHD nonlinear code and linear FAR, both CCFE) – all are resistive MHD codes

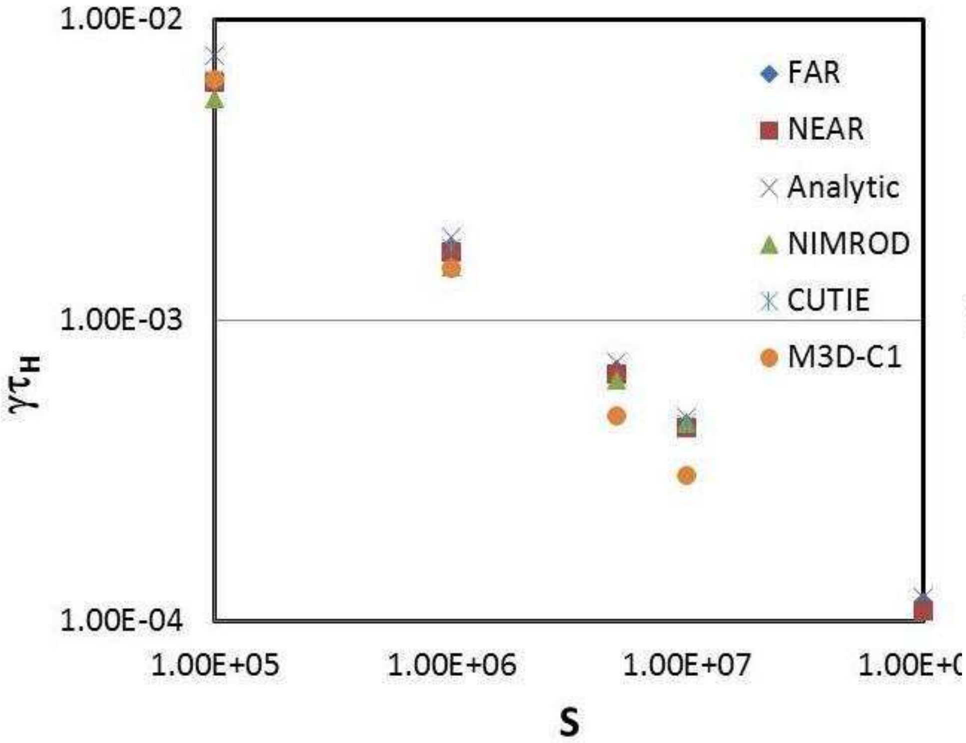
- Steps:-
  - Linear Benchmark (complete)
  - Single helicity nonlinear benchmark (ongoing)
  - 2 helicity nonlinear benchmark no flow
  - 2 helicity nonlinear benchmark with flow (viscosity)

} To be done

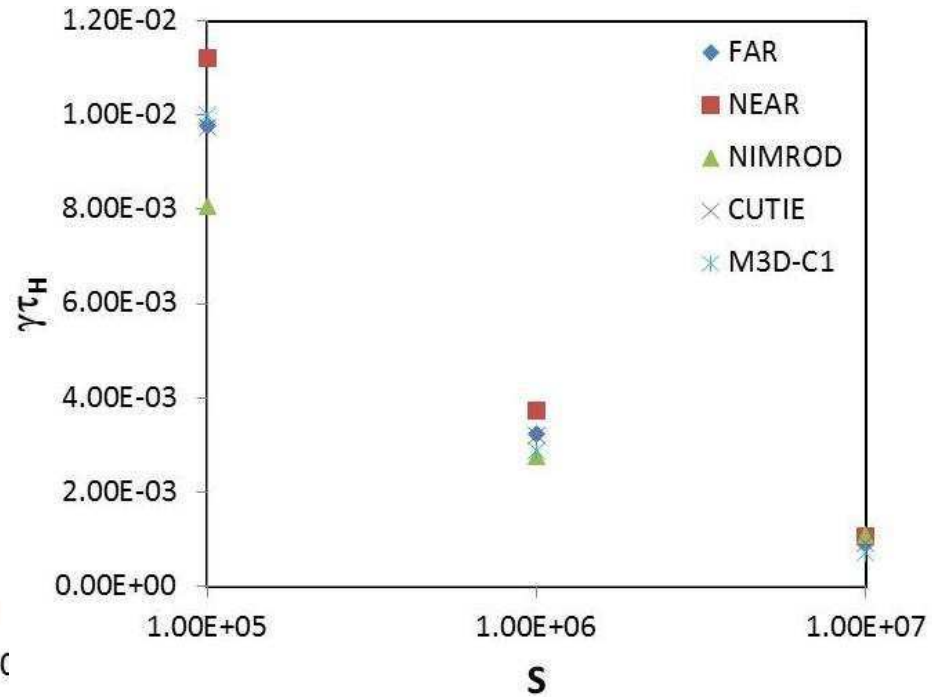
Linear Benchmarking

Cylindrical $q=1.33(1+(r/0.595)^8)^{0.25}$ and $\beta=0$

m=2, n=1



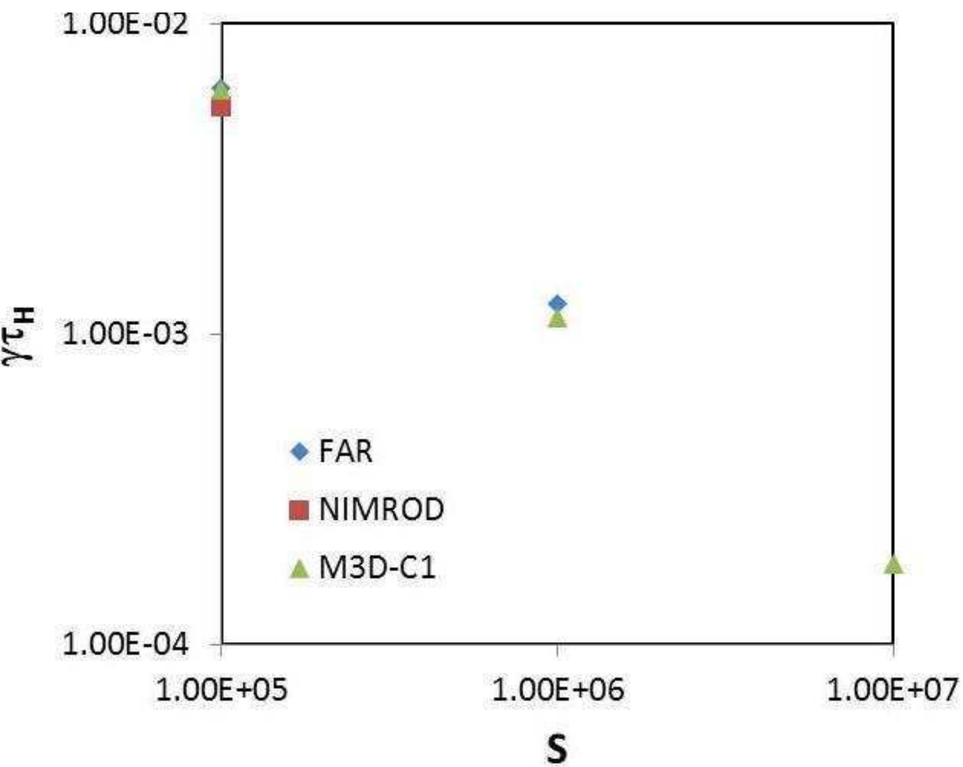
m=3, n=2



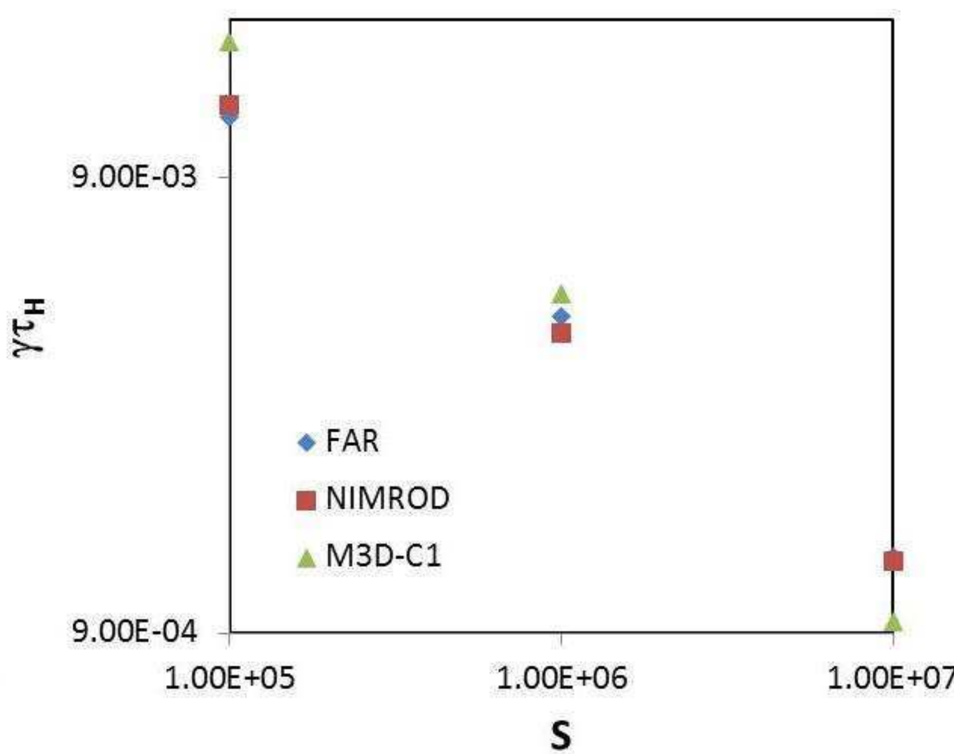
Linear Benchmarking

R/a=10, $q=1.33(1 + (r/0.595)^8)^{0.25}$ and $\beta_0=1.1\times10^{-7}$

m=2, n=1

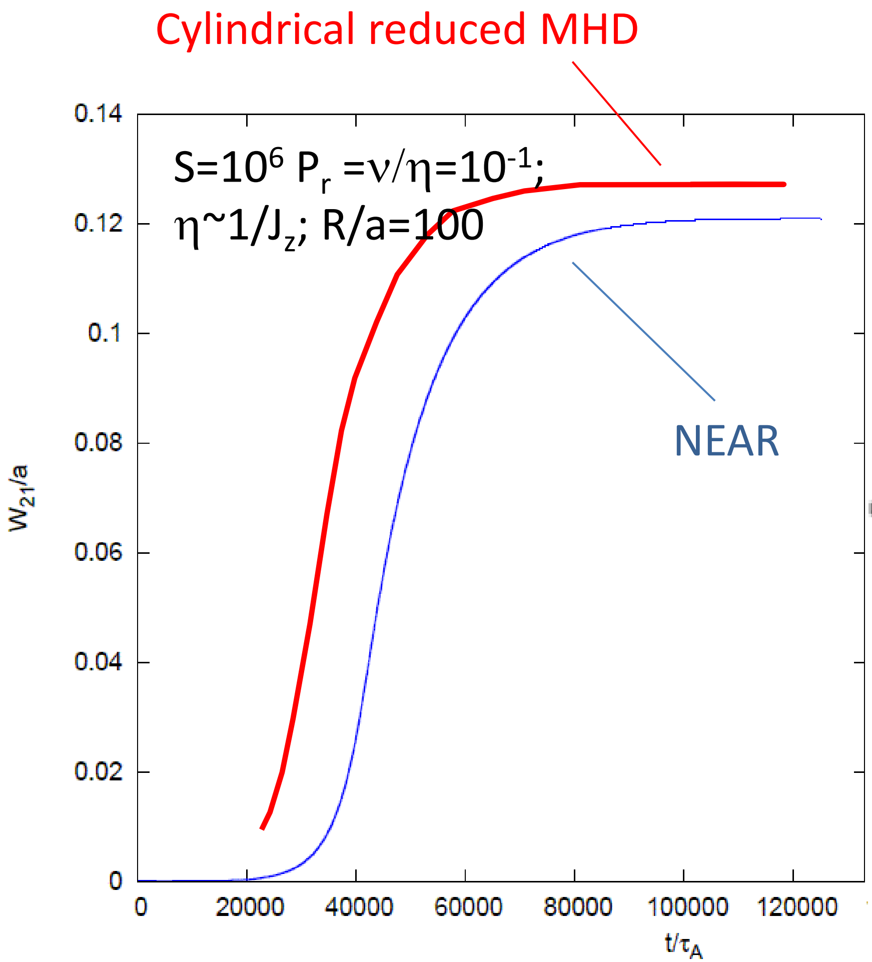


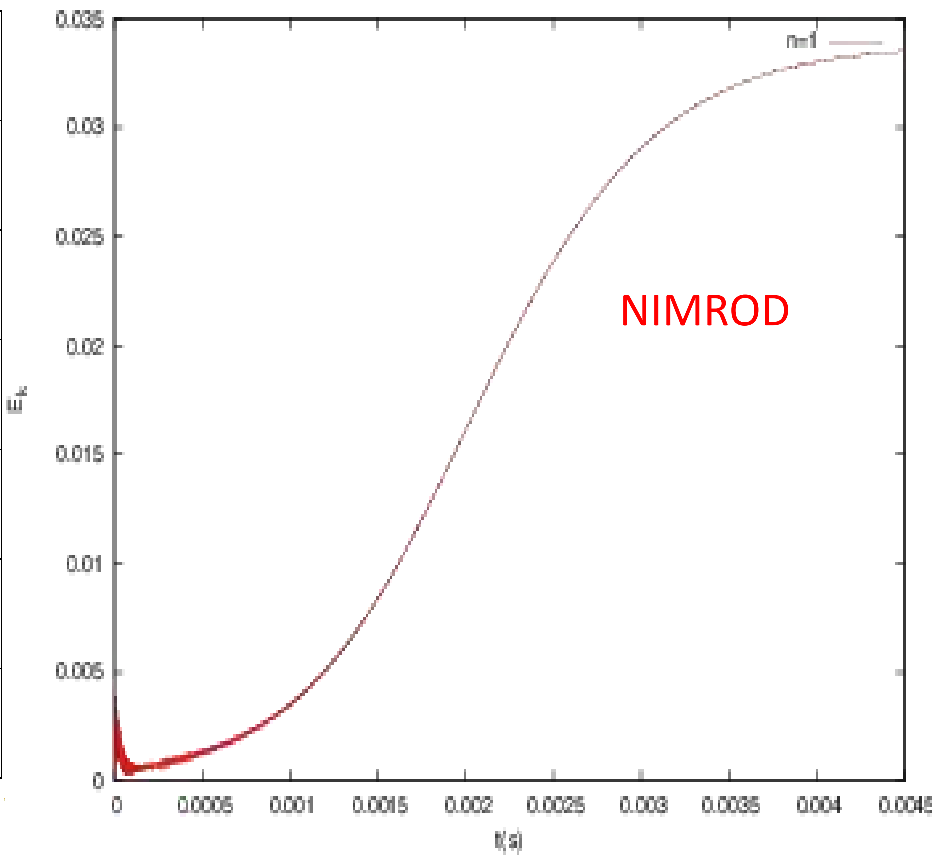
m=3, n=2



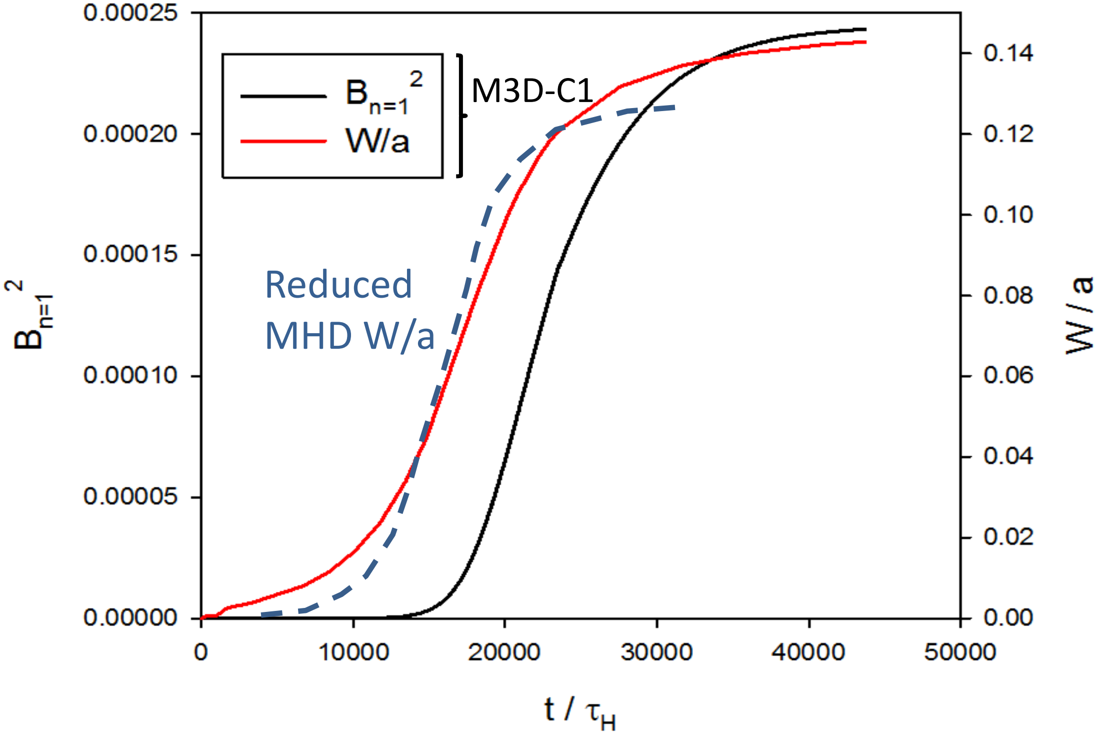
Nonlinear single helicity benchmark

$q=1.15(1 + (r/0.81)^2)$ unstable to n=1, m=2 only ($\Delta'_{2,1}=2.46$, $\Delta'_{3,2}= -0.23$)

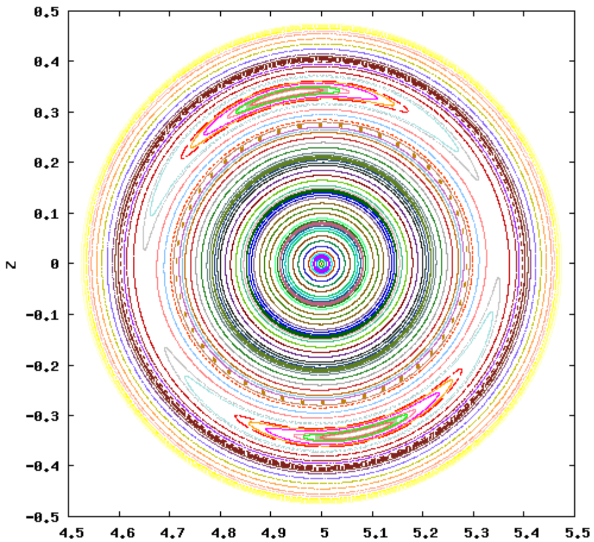




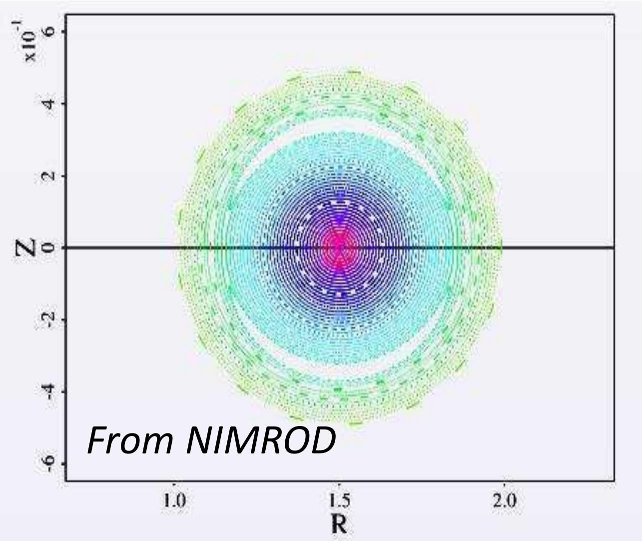
Nonlinear single helicity benchmark - contd



$q=1.15(1 + (r/0.81)^2)$; $S=10^5$, $P_r=0.047$



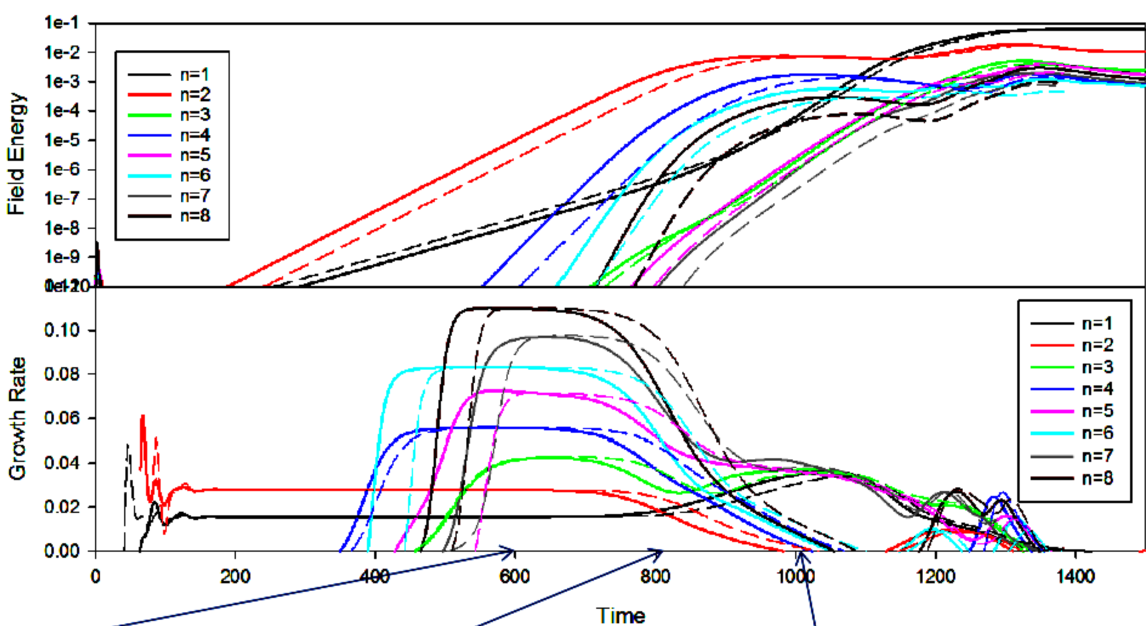
From M3D-C1

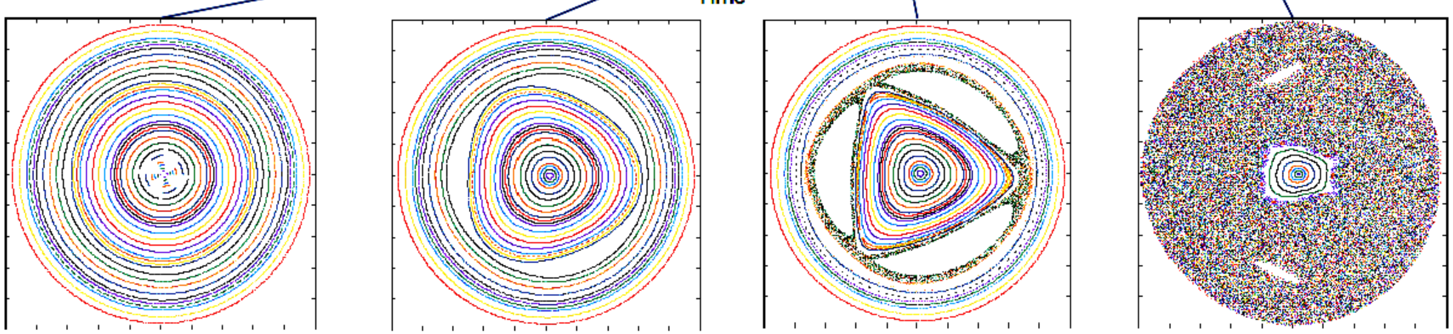


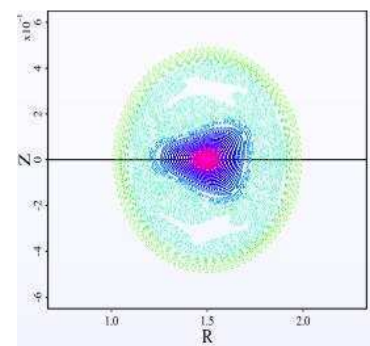
From NIMROD

Nonlinear double helicity benchmark

Mode Growth vs time **for 2 unstable mode case**
Comparison of 16 planes (solid) and 32 planes (dashed)





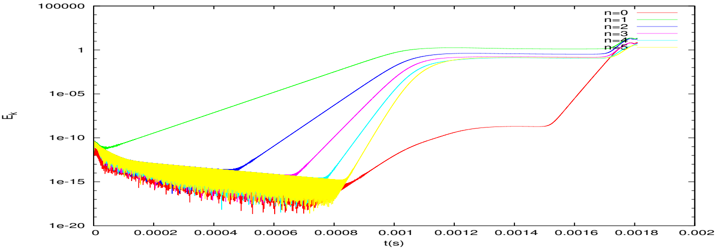


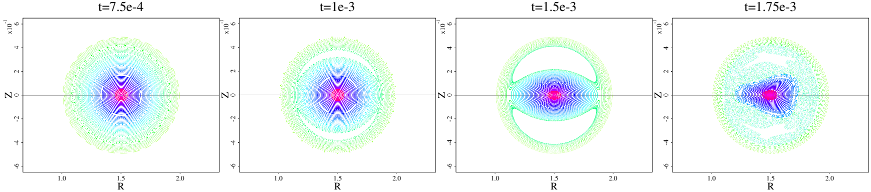
From NIMROD

- The case $q=1.33(1+(r/0.595)^8)^{1/4}$ used for linear calcs is strongly unstable
- Leads to stochasticity (like the ORNL disruption models of 1970/80's)

M3D-C1 with $S=2\times10^4$, $P_r=\nu/\eta=1$

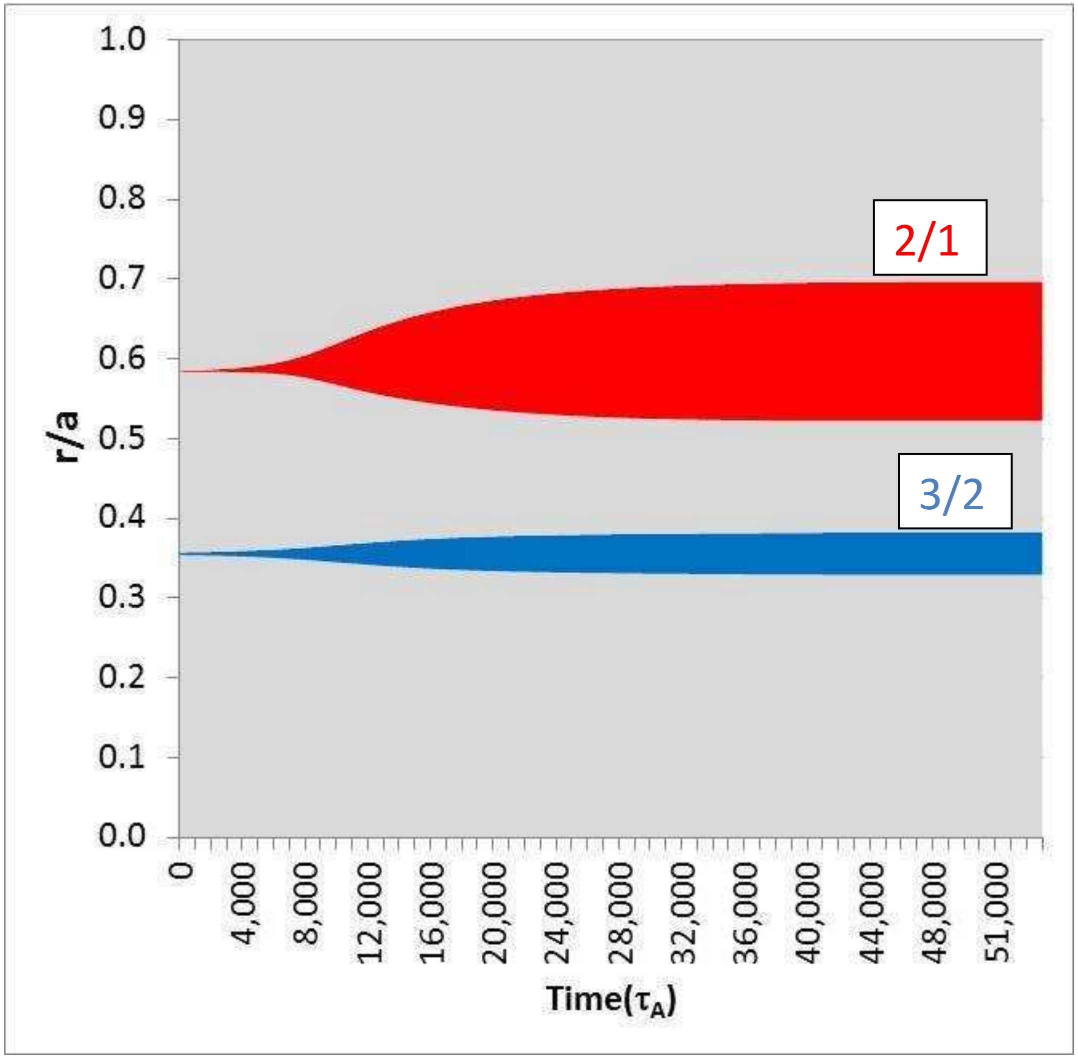
NIMROD nonlinear results on double helicity benchmark case





$$S = 2 \times 10^4, Pr = 1$$

Nonlinear double helicity benchmark



Cylindrical reduced MHD.

$q=1.15(1+(r/0.69)^{1.8})$

$S=10^6$; $\eta=1/Jz$; $P_r=0.1$

$\Delta'_{2/1}=2.936$, $\Delta'_{3,2}=2.56$ and $\Delta'_{4/3}= -0.079$

- Not stochastic, but good candidate for flow profile alteration.

Near term future work

- Complete the benchmark (including nonlinear evolution with 2 helicities)
- Introduce differential plasma rotation
- Full simulations will need viscosity to understand locking effects
- Open to suggestions ……

Acknowledgements

Thanks to JA-2 contributors:-

D Chandra[1], N Ferraro[2], S Jardin[2], R La Haye[3], T Hender[4], W –L Huang[5], E Lazzaro[6], J Mendonca[1], O Sauter[7], A Sen[1], A Thyagaraja[4], B Tobias[2,3], and P Zhu[5,8]

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