Update on NIMROD modeling of edge modes

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SIMULATIONS EMPOWERING
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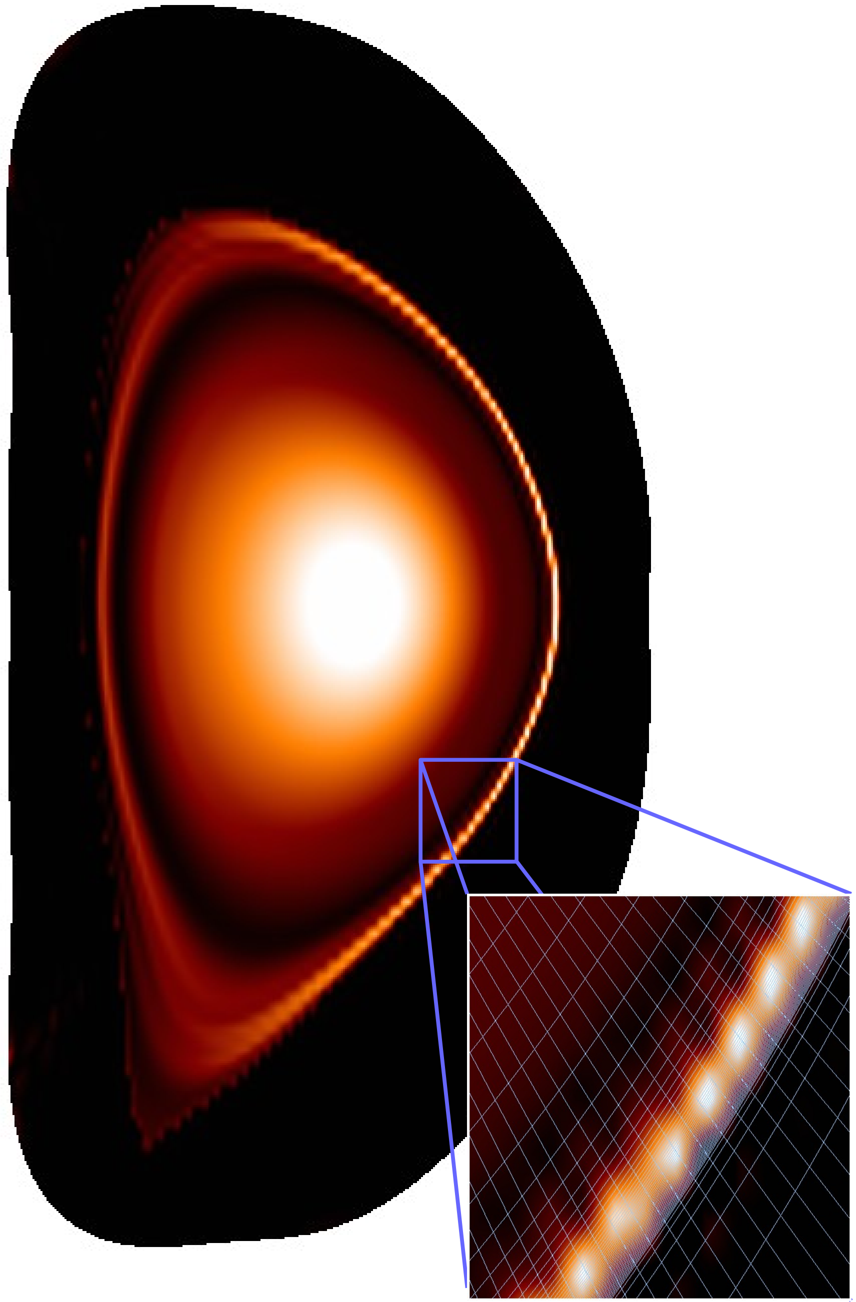
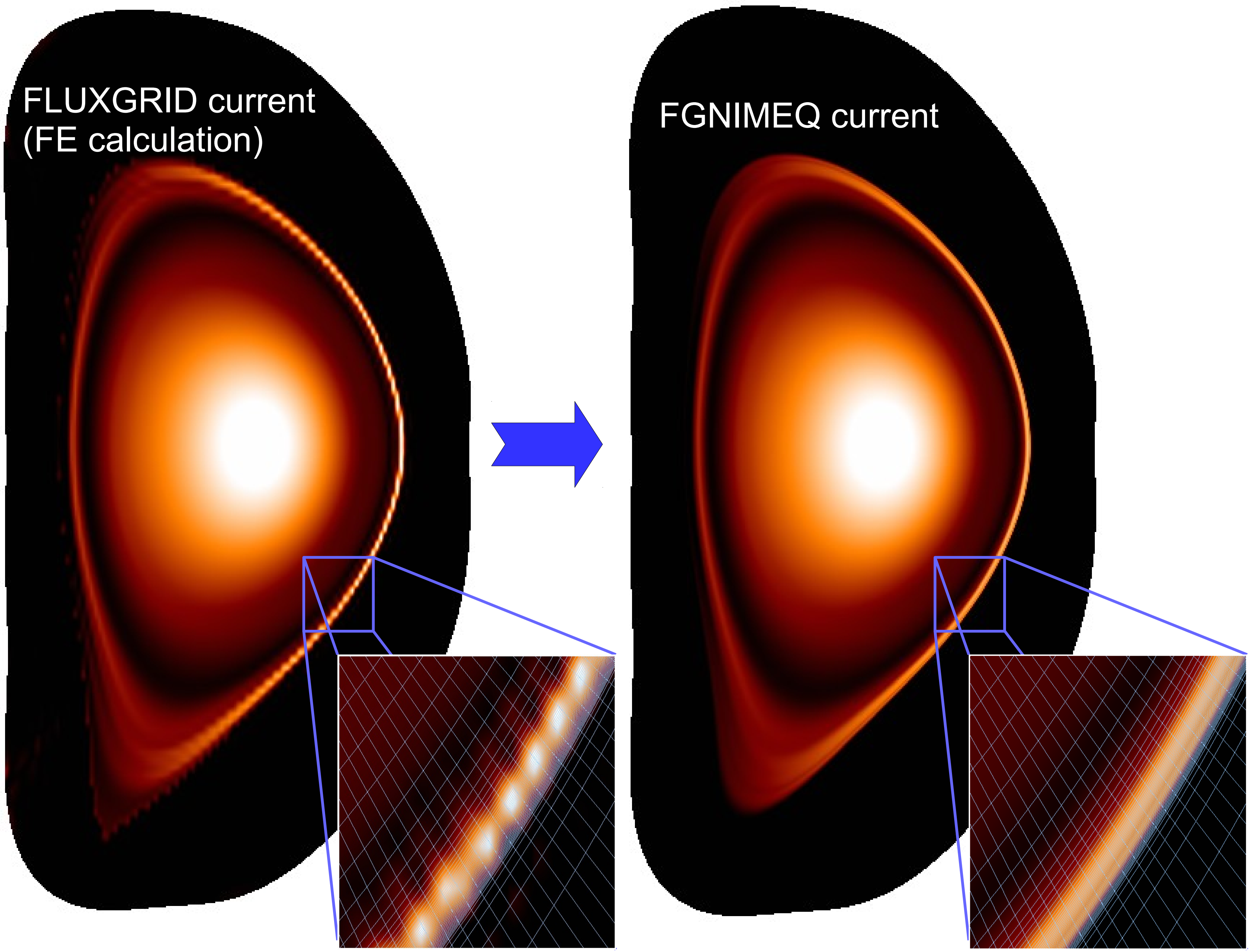
Computations with low resolution reconstructions may be corrupted by the input file resolution.

- Fluxgrid currently maps ψ from the reconstructed grid onto the NIMROD grid.
- Low resolution reconstructions can lead to small scale artifacts in the equilibrium.
  - In particular, the extended-MHD operators, many of which involve high-order derivatives, seem to be sensitive to these artifacts.
- Figure: Toroidal current mapped to a 72x512pd4 NIMROD grid from a 128x128 reconstructed EFIT grid where FE calculations are used to compute J from ψ.



An new utility, FGNIMEQ, allows one to re-solve the Grad Shafranov equation to obtain high quality fields.

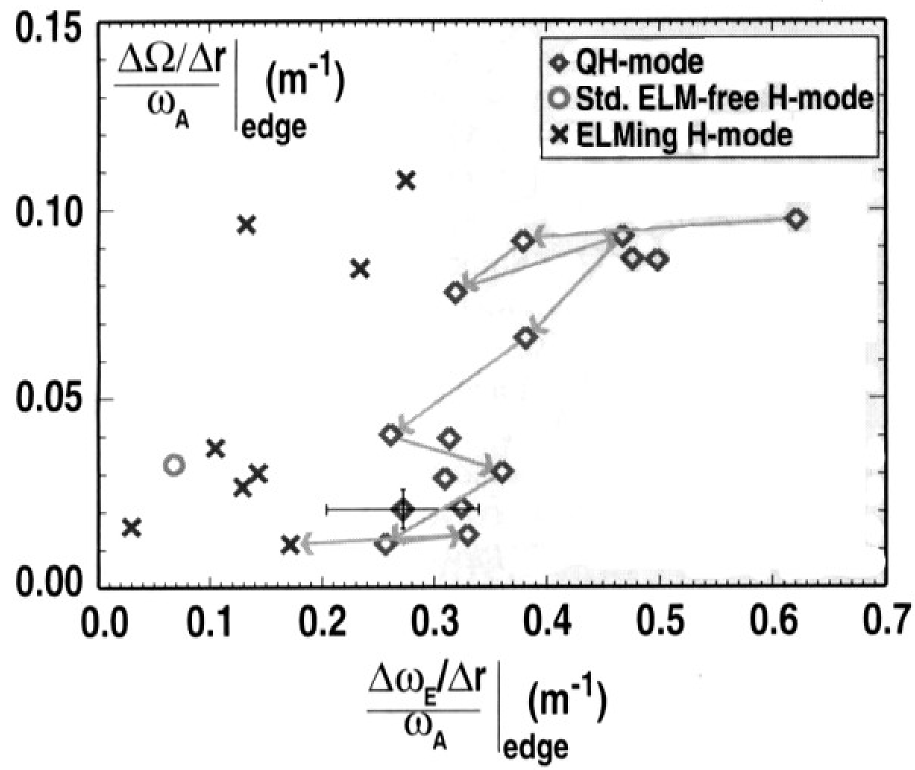


Using FGNIMEQ, we can now converge on extended-MHD cases that were previously problematic.

- FGNIMEQ uses the mapped ψ as a boundary condition and splines of the reconstructed profiles for p and F and re-solves the Grad Shafranov equation with NIMEQ [Howell and Sovinec, CPC 185, 1415 (2014)].
  - The extension for FGNIMEQ is the inclusion of an open flux region and coupling to FLUXGRID.
- The goal is to minimally change the macroscopic equilibrium.
- It has enabled the linear runs of this presentation which do not use any hyper-diffusivities or stabilization methods.
- See my poster (Monday morning) for more details on FGNIMEQ.

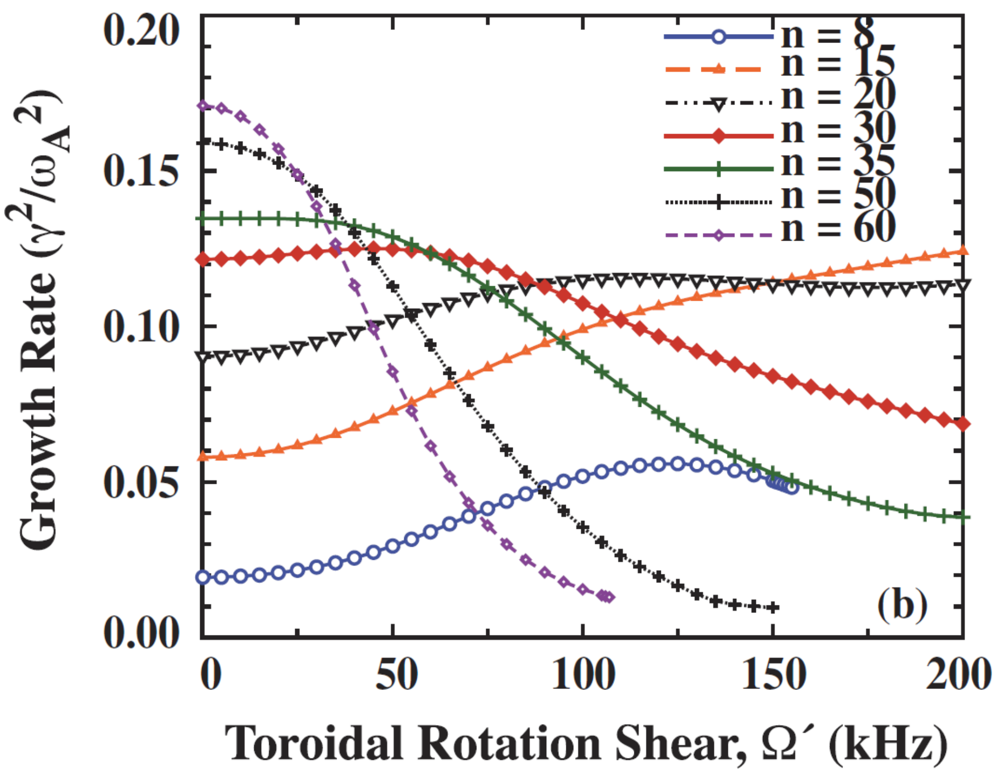
Tokamak operation with edge harmonic oscillations (EHO) provides access to a quiescent H-mode regime [Burrell 2012].

- EHO is characterized by a small toroidal mode number (n~1-5) perturbation localized to the magnetic separatrix.
- Particle transport is enhanced leading to steady-state pedestal profiles.
- Access to the EHO operation regime requires control of the flow profile.
- In particular, experimental observations indicate that the ExB flow shear is a key component in the generation of EHO [Garofalo 2011].



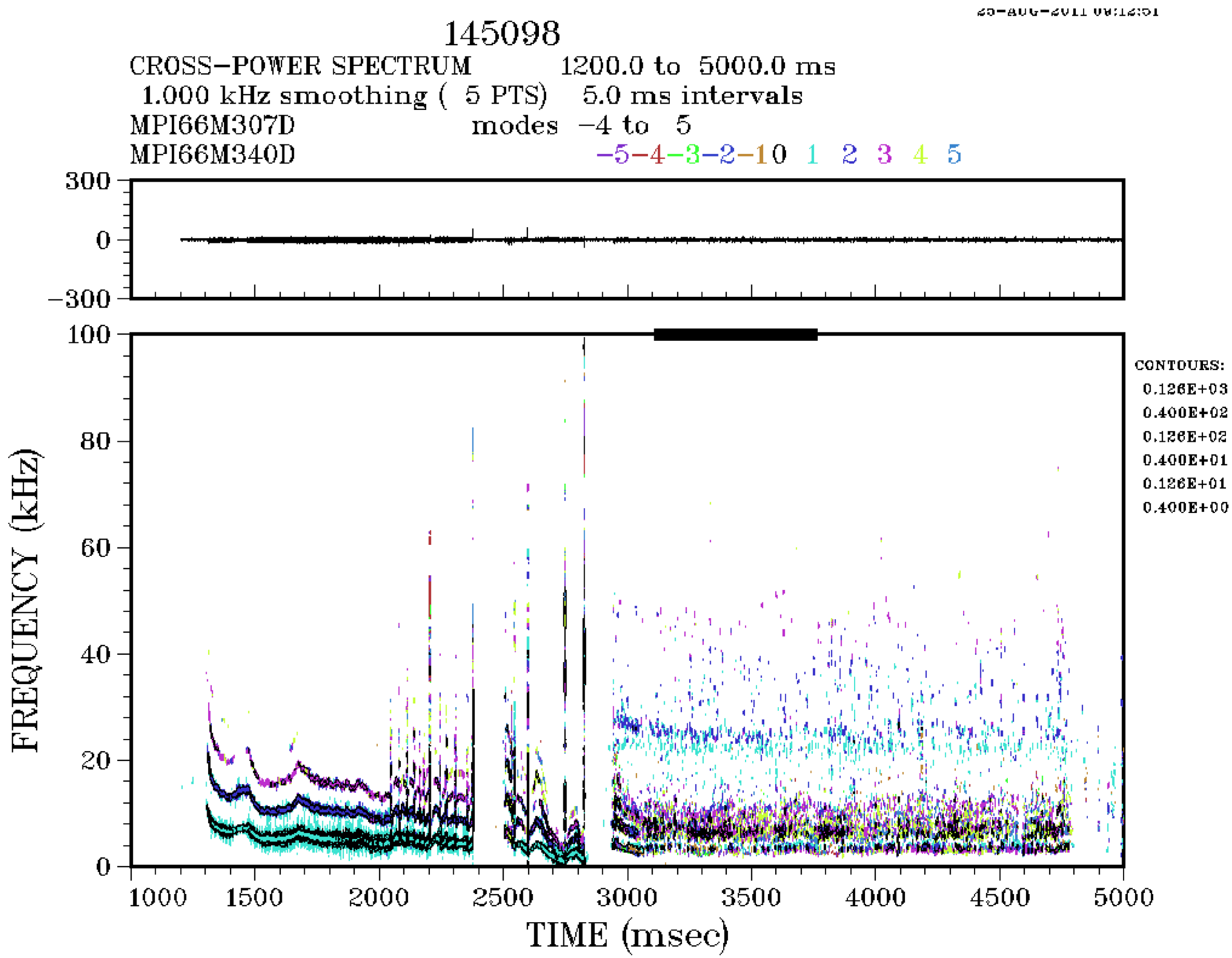
The physical mechanisms of EHO are not fully understood.

- Linear MHD calculations suggest EHO may be a saturated kink-peeling mode partially driven by flow-profile shear [Snyder 2007].
- It is hypothesized that the saturated mode drives sufficient particle and thermal transport to maintain steady state pedestal profiles.



ELITE results from Snyder 2007

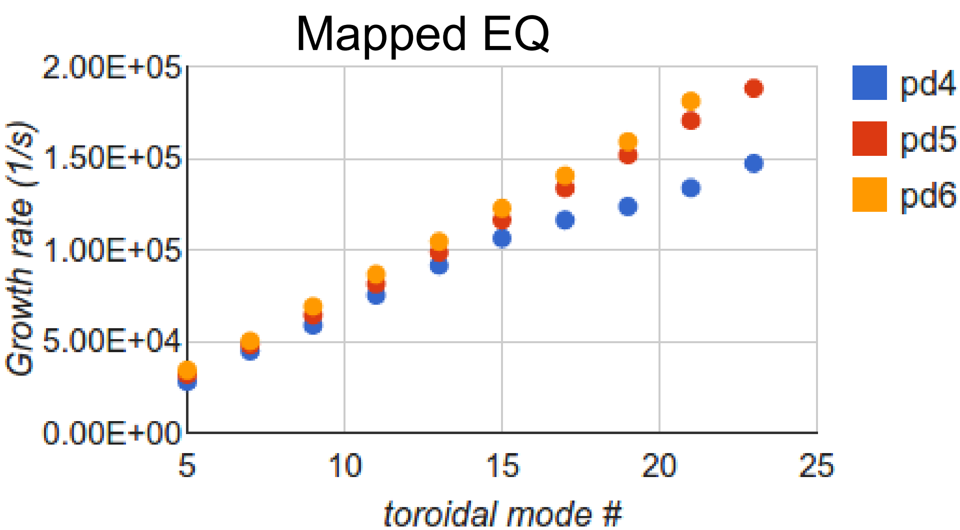
We analyze DIII-D shot 145098 at 4250 ms while the discharge is ELM free with broadband EHO.

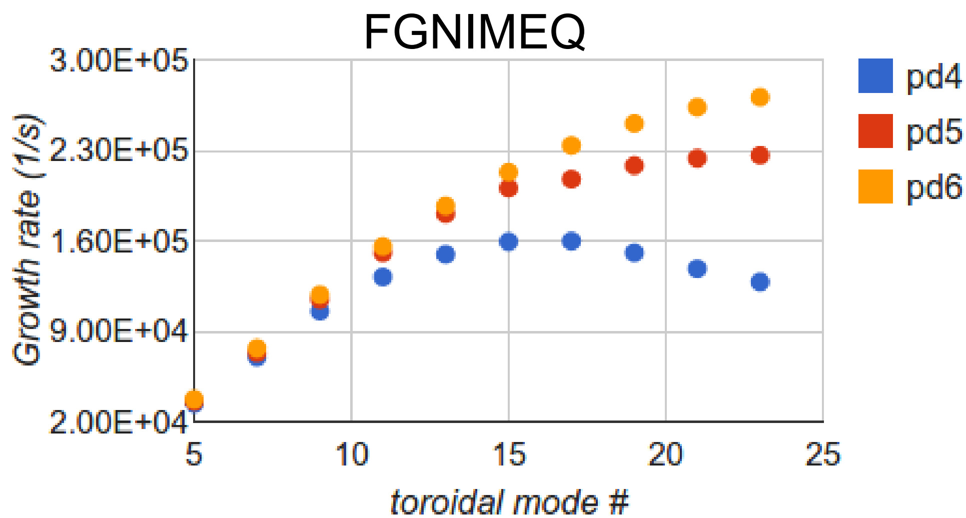


We study a reconstruction of this discharge with varied NIMROD runs.

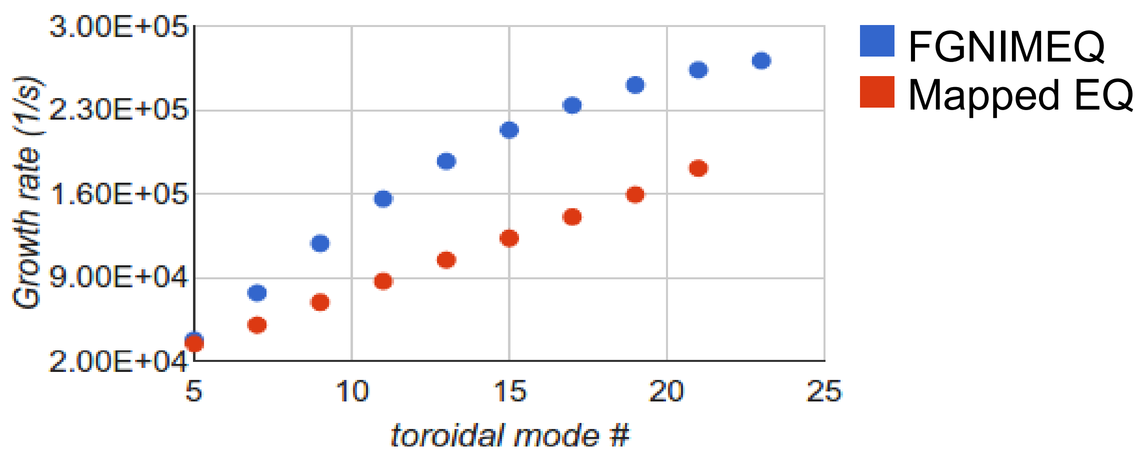
- Model variations (effects are additive)
  - Resistive MHD with parallel closures (par): Density profile, Spitzer resistivity, P_m=1, $\chi_\perp$=0.1η/μ_0, D_n=0.1η/μ_0, parallel viscosity $\nu_\parallel$=8.6e5m²/s, parallel thermal conduction $\chi_\parallel$=1e7m²/s.
  - Ion gyroviscosity (gyr)
  - Two fluid (2fl): generalized Ohm's law
  - Separate temperature evolution (2t): cross heat fluxes included.
- Bootstrap current variations: reduced/full
- Flow effect variations: V_{ExB}, V_{Kpol} and V_* can be included.

FGNIMEQ allows modeling that was not previously possible and makes other cases more robust.



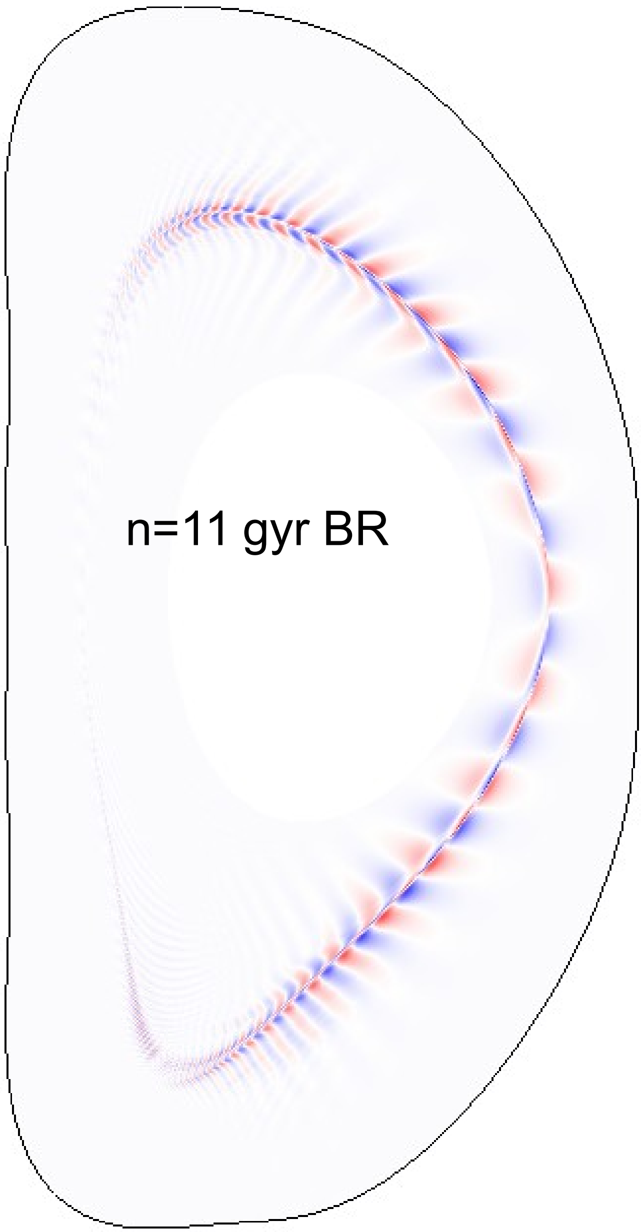


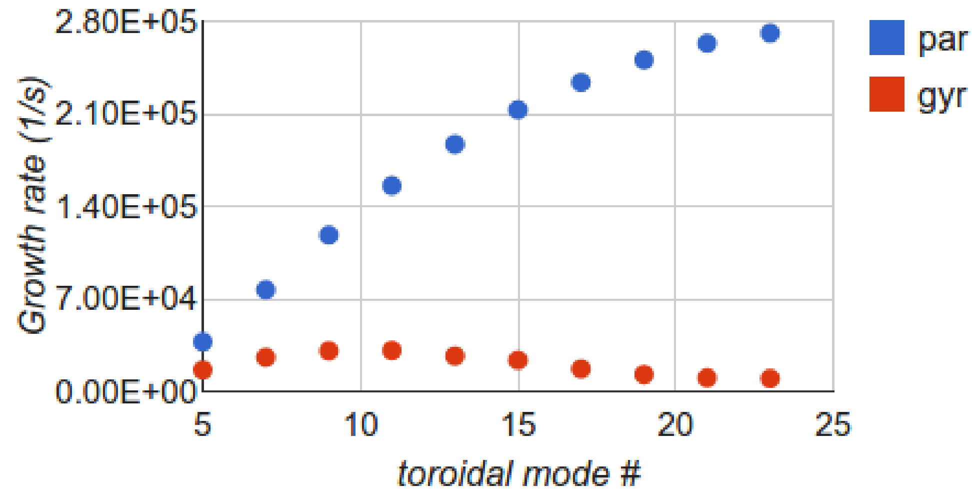
- Parallel model is used in all cases.
- The mapped EQ cases require a FE stabilization method on the velocity in order to converge.
- Extended-MHD cases are not possible with the mapped EQ.
- The growth rate is similar at small toroidal mode number.

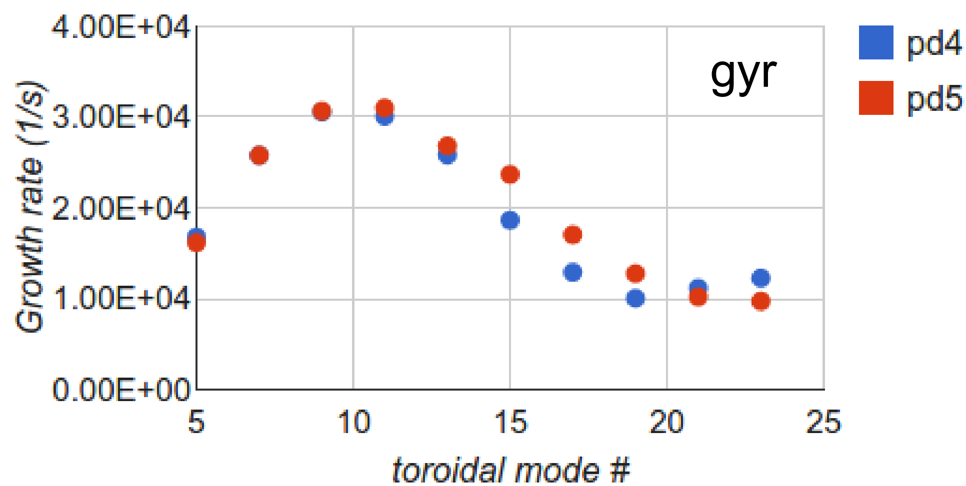


50% bootstrap current

Ion gyroviscosity alone is stabilizing; many drift-ordered terms are neglected with this model.



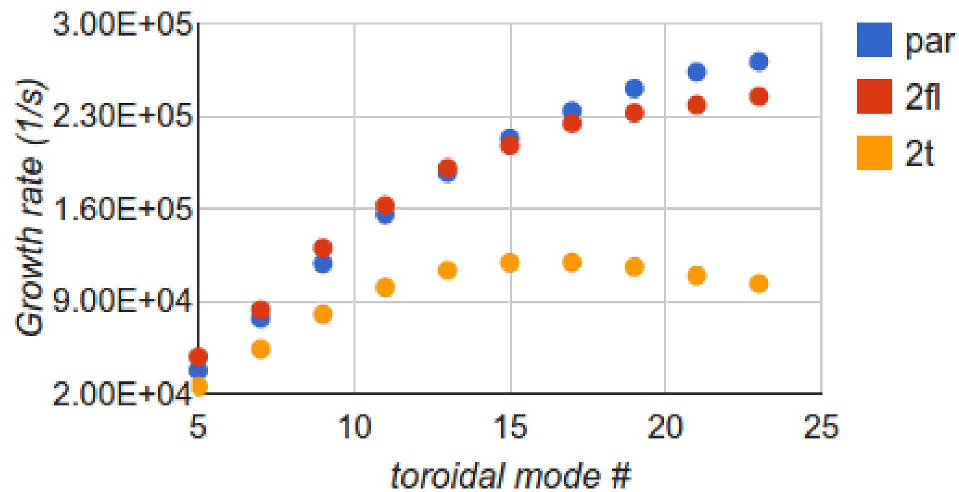


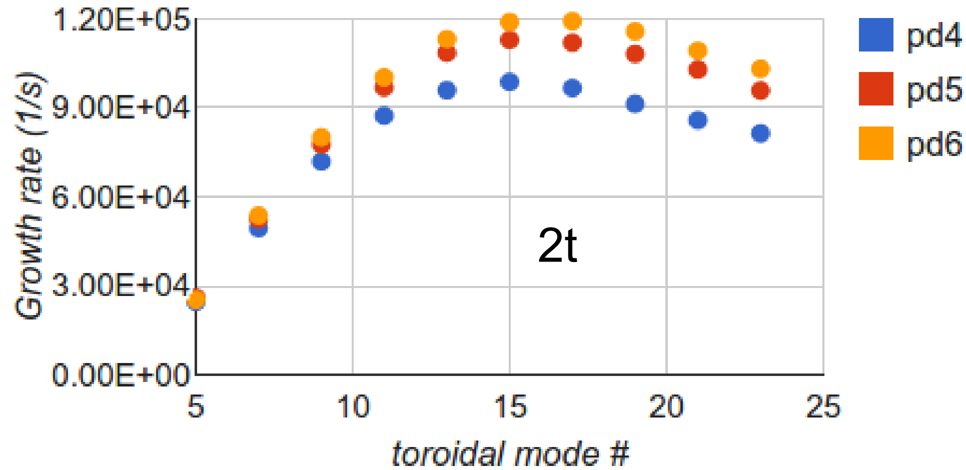


50% bootstrap current; $d_i(\psi_n=1)=0.1\text{m}$

Two fluid modeling captures large stabilizing drift effects.

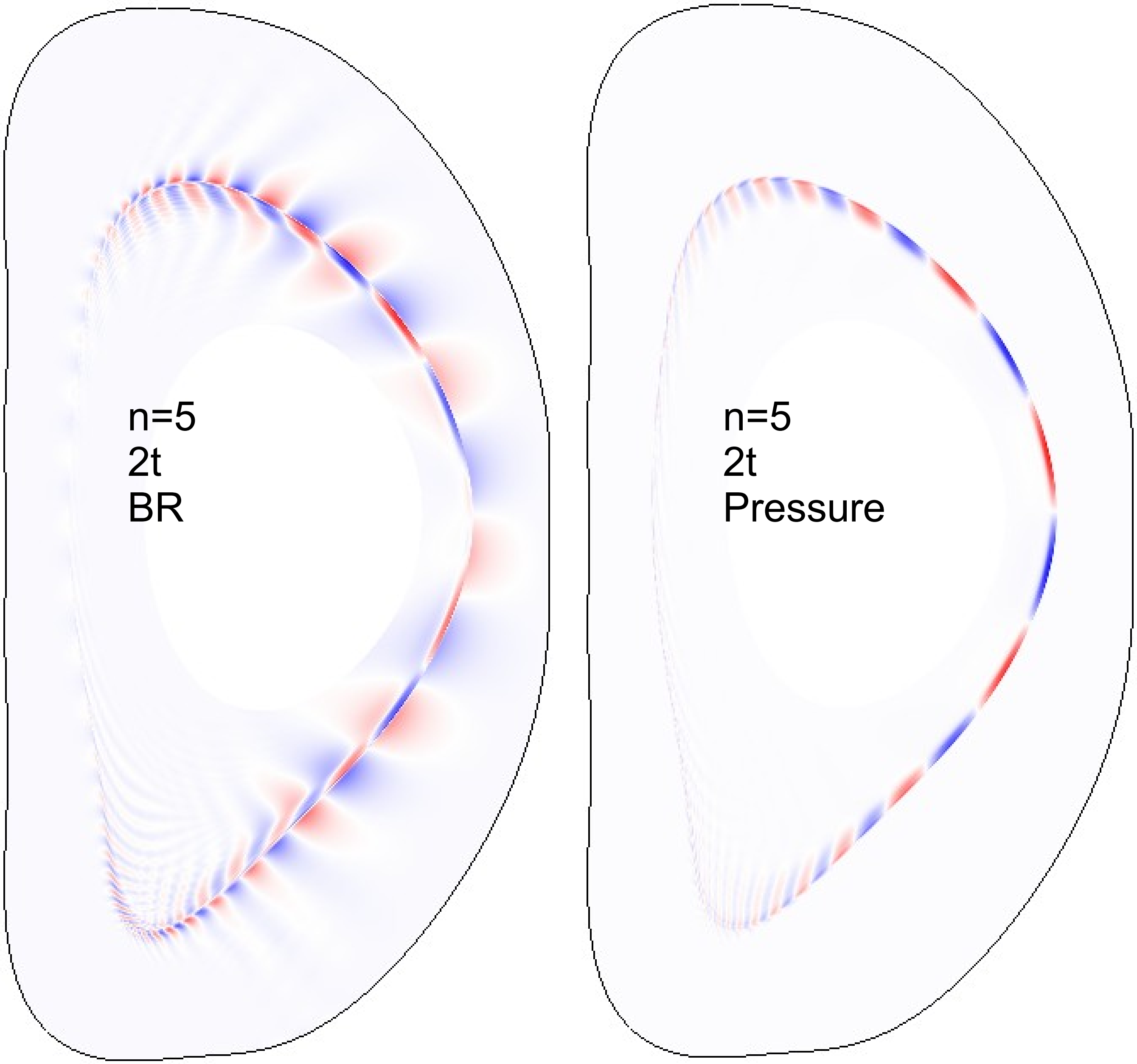
- For the drift-tearing, our recent publication showed the importance of cross-heat flux to the drift stabilization at low β [PoP 21, 102113 (2014)].
- Although modeling with a generalized Ohm's law and ion gyroviscosity is slightly stabilizing, large stabilizing drift effect is obtained with a two temperature modeling.





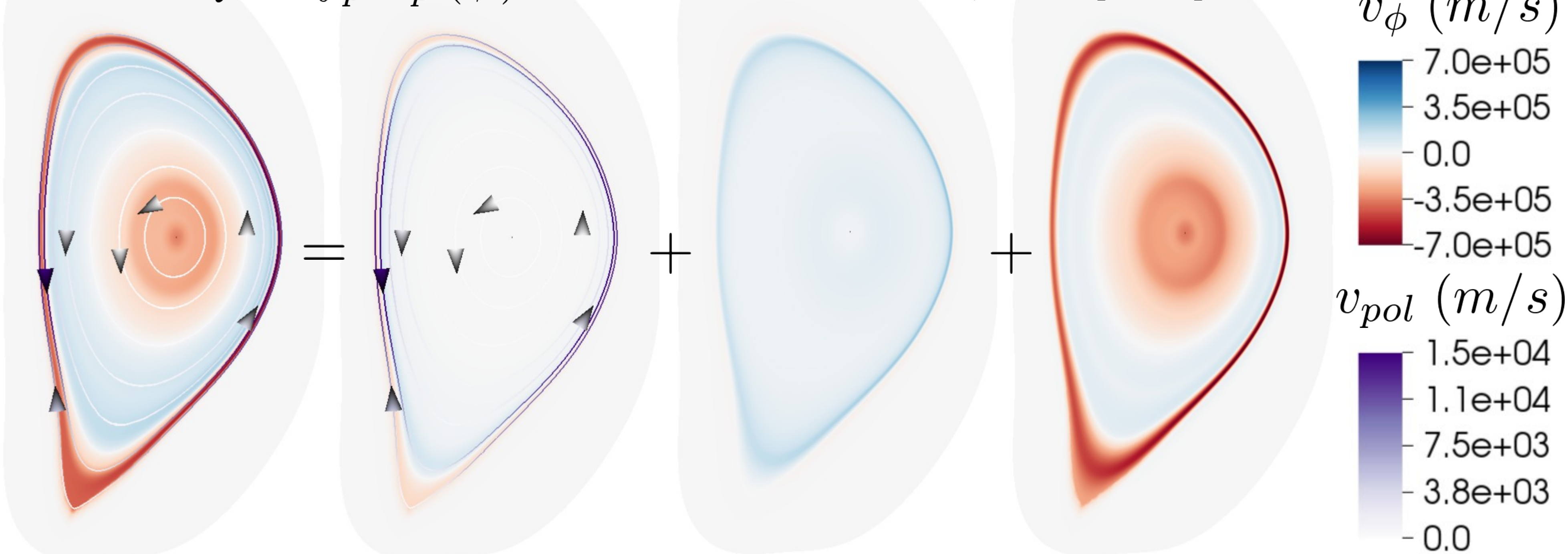
50% bootstrap current; $d_i(\Psi_n=1)=0.001$m

Extended-MHD modeling does not produce macroscopic changes in the mode structure.



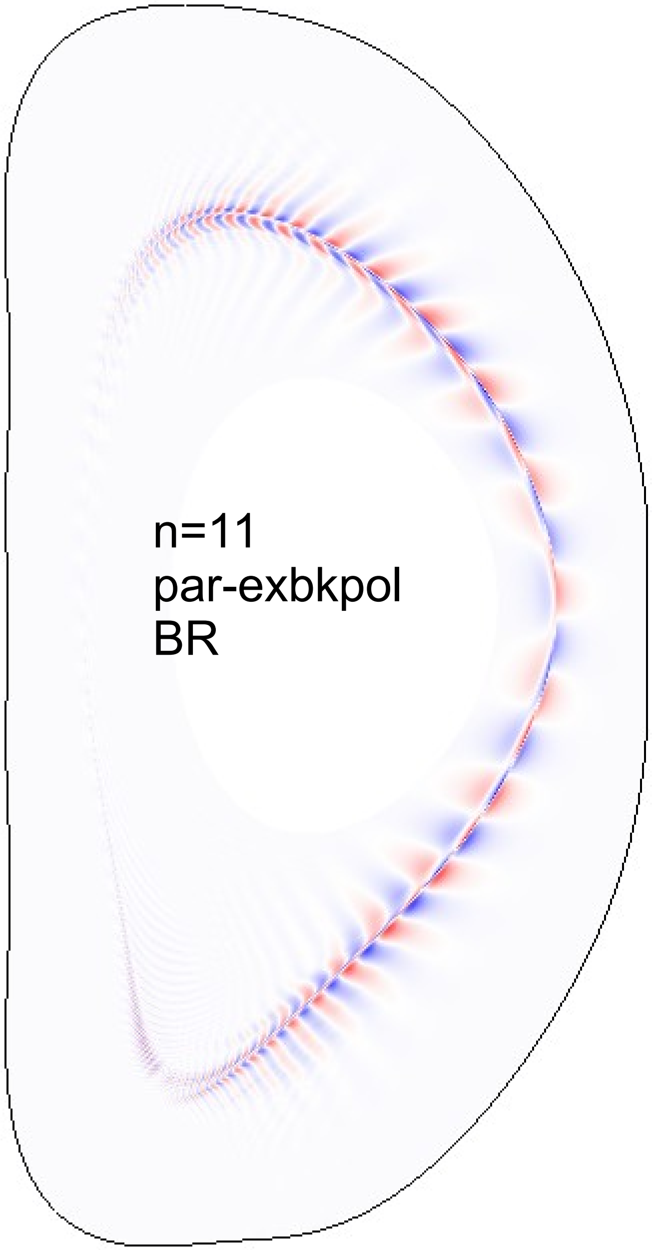
Going forward we intend to focus on modeling cases with flow and nonlinear dynamics.

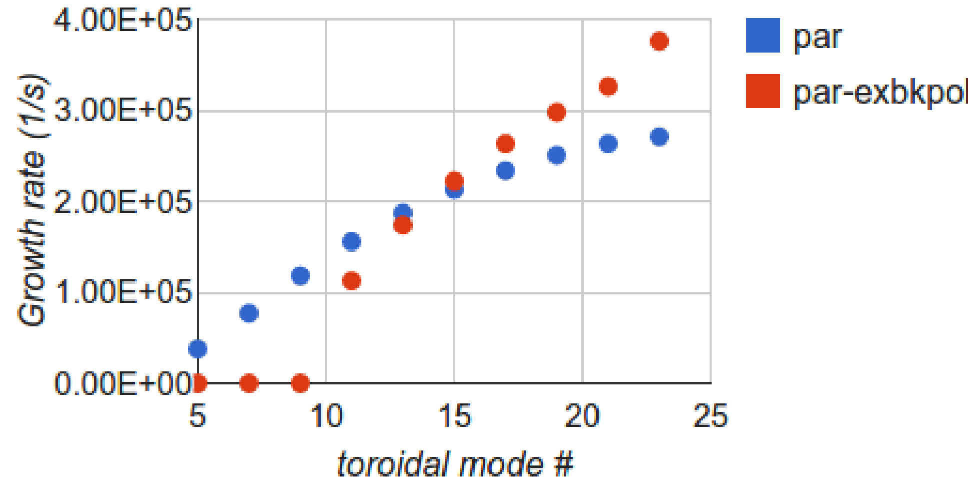
$$\mathbf{v}_{EQ} = f_p K_p(\psi)\,\mathbf{B} + f_{E\times B}\Omega_{E\times B}R\hat{\phi} - f_{\nabla p}\Omega_{\nabla p}R\hat{\phi}$$



- We can vary the each contributions flow profiles, here we run cases with and without the ExB flow contribution.
- Profiles are shown for $f_p = f_{E\times B} = f_{\nabla p} = 1$.
- Flows are specified by the reconstruction up to the separatrix and extrapolated to zero beyond the separatrix. The extrapolation methods are a work in progress.

Flow effects stabilize the intermediate toroidal mode number modes.



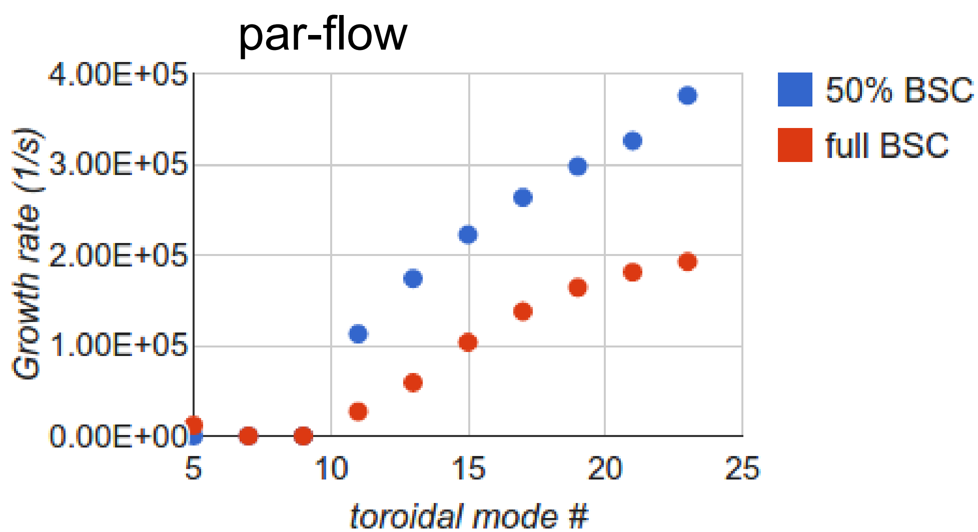


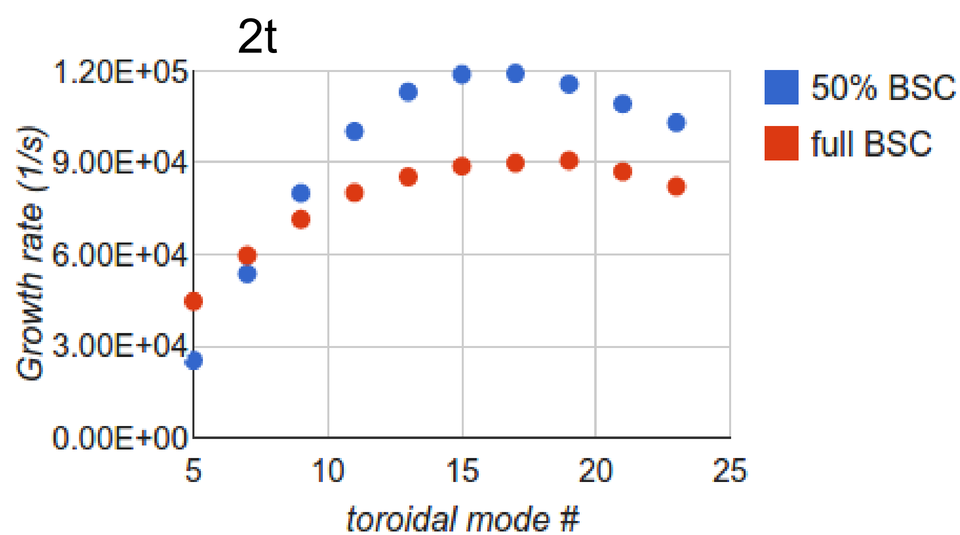
- ELITE results on previous slide had high-n stabilization (n=35-60) and intermediate-n destabilization (n=8-15).
  - However these results are not from the same reconstruction!

50% bootstrap current

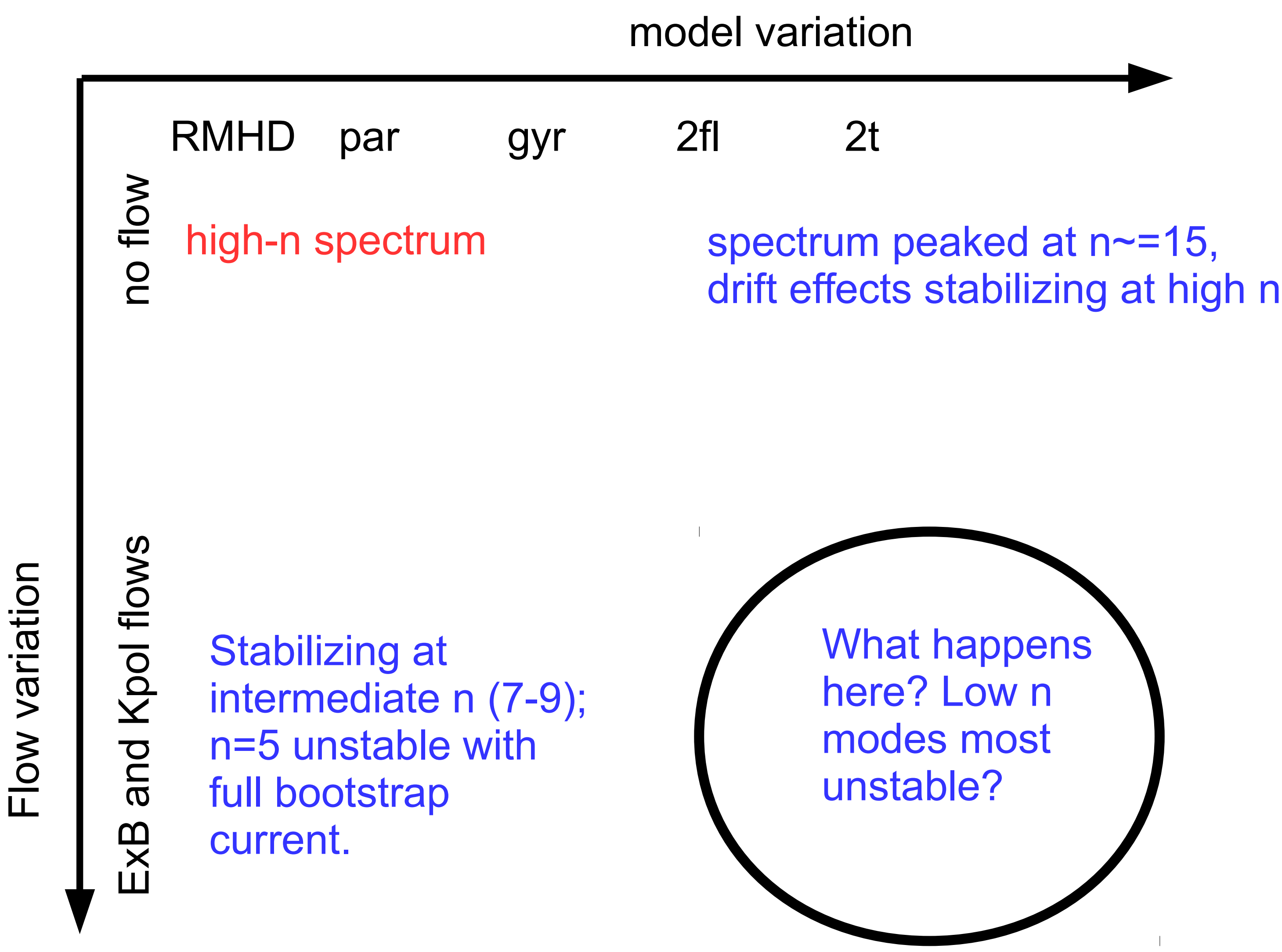
Including the full bootstrap current destabilizes the low-n modes and stabilizes the high-n modes.

- The n=5 mode is unstable with a full BS current and a parallel flow model but stable with the same model and 50% BS current.
- The safety factor has reversed shear at full BS current, and low destabilization is expected [Zhu et al. PoP 19, 022107 (2012)].
- Future work will concentrate on combining the two-fluid, two-temperature modeling with flow profiles (which also will include a diamagnetic flow that enters as a drift-ordered effect).





Additional modeling is required.



Summary

- FGNIMEQ is a new utility that re-solves the Grad Shafranov equation for high-quality fields.
  - It is particularly useful for edge cases and low resolution reconstructions.
- With this new capability we are now able to run extended-MHD cases with the EHO reconstructed equilibrium.
- We find flow effects are stabilizing and intermediate n, and drift effects from extended-MHD are stabilizing at high n.