Gyroviscosity-induced FLR Effects on Peeling-Ballooning Instability

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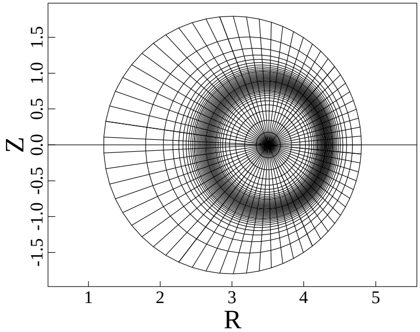
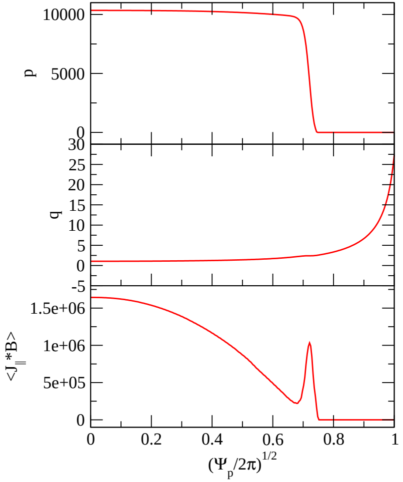
Motivation

- Recent ideal and resistive simulations of nonlinear peeling-dominant edge instability
  - Show formation of blob-like structure [Burke *et al.* , 2010],
  - May explain the large ΔW scaling in high collisionality regime.
- Do FLR effects significantly change ideal/resistive peeling simulation results?
  - H-mode pedestal width $L_p \propto \sqrt{\epsilon}\rho_i \propto \sqrt{\beta_{\text{ped}}}$
  - Determine linear spectrum (high *n* end)
  - ω_* rotation may help break off RT filaments (-> blob formation) [Zhu *et al.* 2007].

Circular-shaped tokamak equilibrium is used





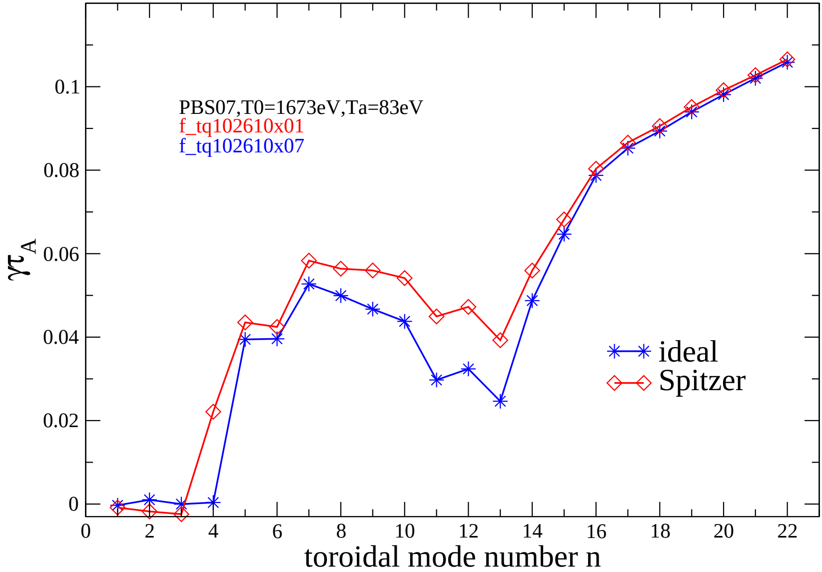
- Equilibrium from TOQ solver
- Finite element mesh used in NIMROD simulation.

Physical scales and regimes for the configuration

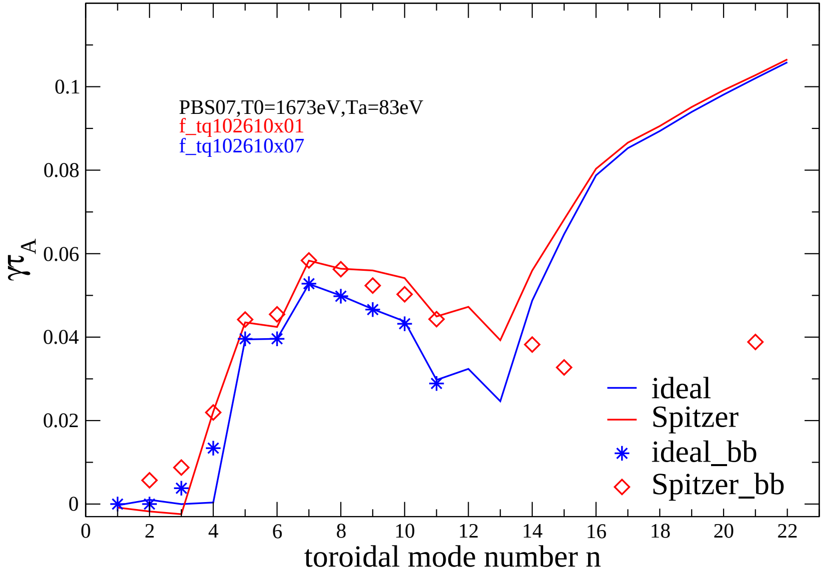
$$R_0 = 3, \quad a = 1.8, \quad L_p \sim 0.1, \quad \rho_i = 10^{-4} \sim 10^{-3} L_p$$
$$\rho/m_i = 2 \times 10^{19}, \quad T_i = 1673 - 83\mathrm{eV}, \quad \beta_t \sim 0.3\%$$
$$u_A = 6.85 \times 10^6, \quad v_{Ti} = 4 \times 10^5, \quad u_{*p} = \frac{\rho_i}{L_p} v_{Ti} \sim 4 \times 10^2$$
$$\omega_{ci} = 10^8, \quad \tau_A = 4.39 \times 10^{-7}, \quad \gamma_{n=7} \sim 10^5, \quad \omega_{*i} \sim 6.7 \times 10^2 n$$
$$S = 3.803 \times 10^8, \quad \tau_R = 1.67 \times 10^2$$

Regimes	ideal	resistive ($\eta \neq 0$)	dissipative ($D, \mu, \chi \gtrsim 0$)
mhd	x	x	
hall ($d_i \neq 0$)			
2fl ($d_{i,e} \neq 0$)			
gyr_visc ($\rho_i \neq 0$)	x	x	
hall+gyr_visc			
2fl+gyr_visc			

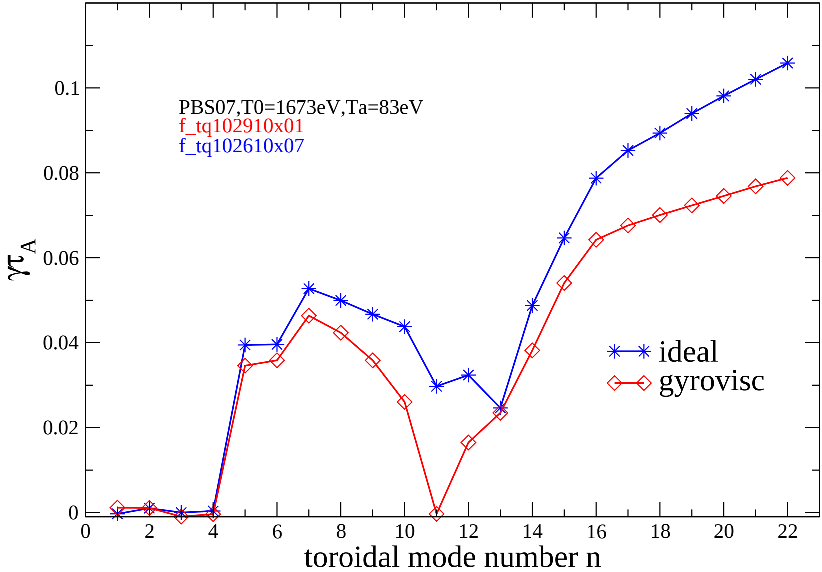
Linear growth dispersion has both low-n peeling components and high-n ballooning components



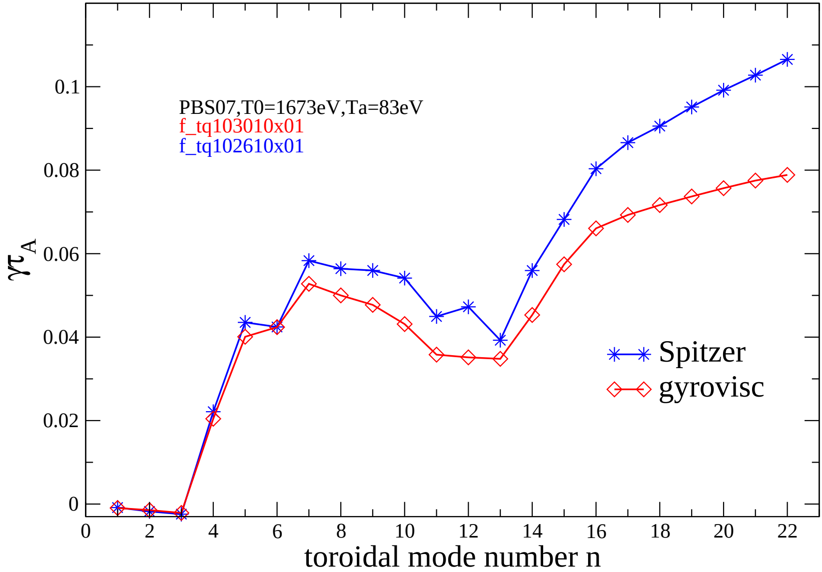
Linear growth dispersion is close to converged values for low-n peeling components



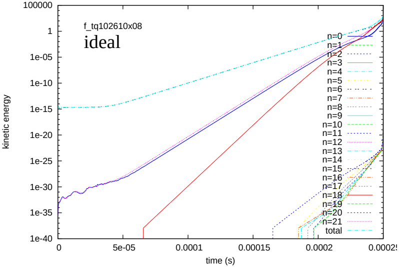
Gyroviscosity has a surprisingly strong FLR stabilization on low-n peeling components

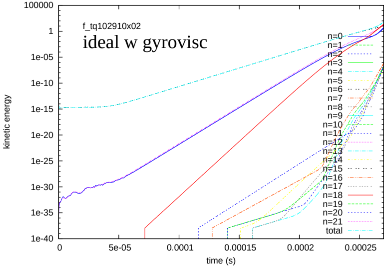


In resistive regime gyroviscous-FLR stabilization more effective on high-n ballooning components



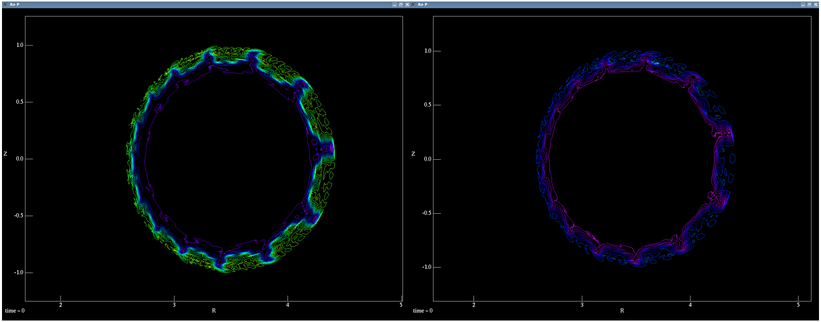
In ideal regime, nonlinear peeling growth slows down mostly due to gyroviscous stabilization of linear peeling growth



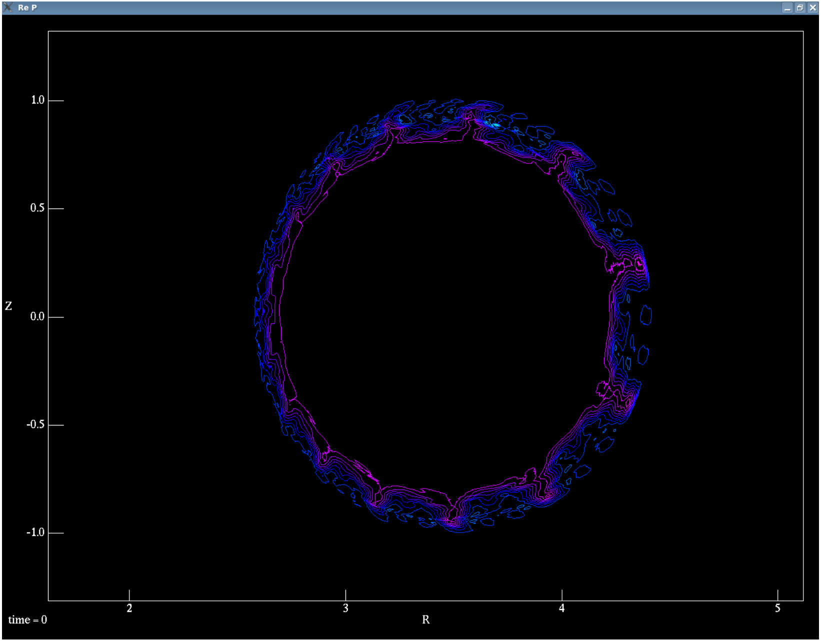


- Initialized with $n = 6$ component; nonlinear simulations include 22 toroidal modes.
- Main nonlinear dynamics are nonlinear harmonic couplings (beatings).
- Gyroviscosity does not qualitatively change nonlinear growth (mostly because linear n=6 growth are very close).

In ideal regime, nonlinear peeling pattern rotates poloidally due to gyroviscous induced ω_* effects

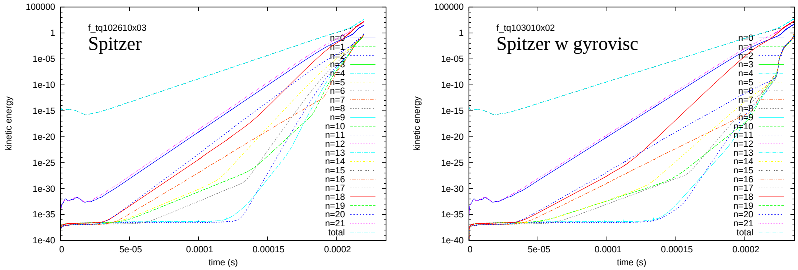


- Left: ideal, t=2.48E-4; Right: ideal & gyrovisc, t=2.72E-4
- Rotates poloidally
- Finger width narrower
- Otherwise similar



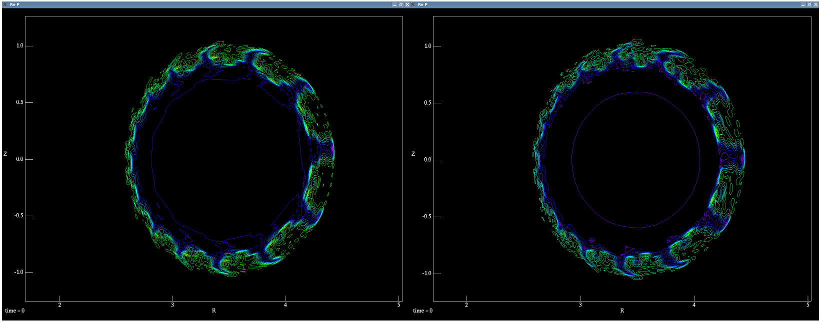
Re P
1.0
0.5
Z
0.0
-0.5
-1.0
2
3
4
5
R
time = 0

In resistive regime, nonlinear drives are stronger for high-n components than in ideal cases



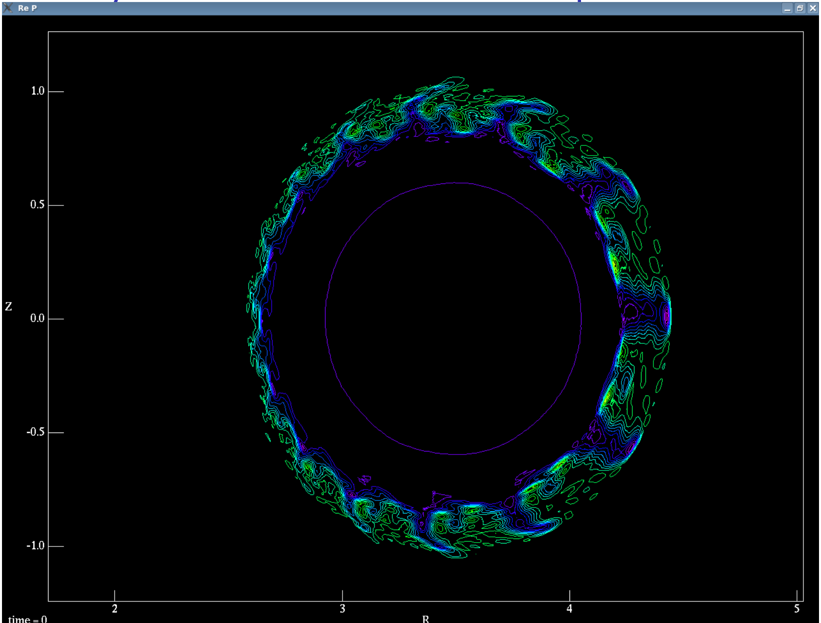
- Initialized with $n = 6$ component; nonlinear simulations include 22 toroidal modes.
- Main nonlinear dynamics are nonlinear harmonic couplings (beatings), but high-n modes are driven faster to larger magnitude
- Gyroviscosity does not qualitatively change nonlinear growth.

In resistive regime, nonlinear peeling patterns appear similiar with or without gyroviscosity



- Left: Spitzer, t=2.20E-4; Right: ideal & gyrovisc, t=2.36E-4

Spitzer resistivity and gyroviscosity case: Nonlinear secondary filaments are more developed



Summary

- Gyroviscosity can effectively reduce the growth rates of both peeling and ballooning components of edge instability.
- Gyroviscous-FLR stabilization of peeling instability appears to be stronger in ideal regime than in resistive regime.
- Gyroviscous-FLR stabilization of peeling-ballooning instability is in general partial (i.e. no complete stabilization) for $n \lesssim 22$.
- Gyroviscosity does not seem to qualitatively change nonlinear mode structure.
- Next
  - Theory for gyroviscous-FLR stabilization of peeling?
  - Two-fluid effects, more challenging.