Microtearing Simulations in the Madison Symmetric Torus

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Overview

- PPCD discharges in MST have lower activity of large scale tearing modes, allowing microinstabilities to play a larger role in transport
  - ITG/ETG, TEM, KBM, microtearing
- Desirable to know more about the nature of microinstabilities in the RFP
  - beta/gradient thresholds
  - parameter dependencies
  - driving mechanisms
- Due to temperature gradients and beta values, microtearing is thought to be an important instability for consideration
- These issues are investigate through a series of linear gyrokinetic simulations are carried out in an RFP equilibrium

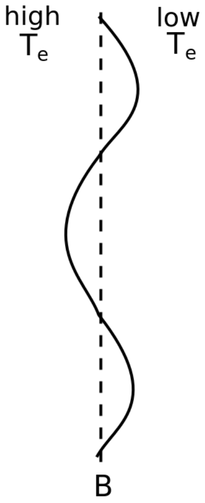
Thermal force drive at high collisionality

Hazeltine et al. (1975), Drake and Lee (1977), Gladd et al. (1980), Hassam (1980)

- electrons stream along perturbed magnetic field
- electron-ion collisions result in frictional force along this field
- an energy dependent collisionality links this frictional force to the temperature gradient

$$F_{th} \sim n_e \nabla_{\parallel} T_e$$

- due to the temperature gradient, the force on electrons coming from different directions does not balance and a current may be generated
- current can reinforce original magnetic perturbation



Trapped particle drive at moderate collisionality

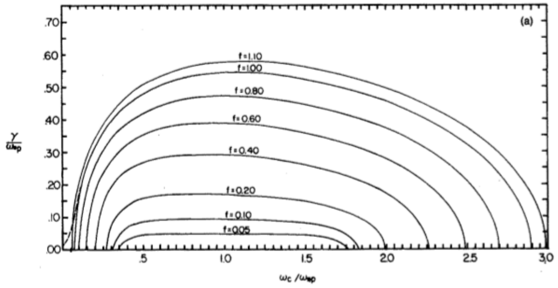
Catto and Rosenbluth (1981), Connor et al. (1990)

- trapped particle effects become important at lower collisionalities
- particles scatter between passing and trapped, increasing effective collisionality
- current flows through the passing particles in the collisional boundary layer
- requires energy dependent collision operator

Magnetic Curvature-Drift Instability

Finn and Drake (1984,1986)

- a semi-collisional drift tearing mode that for instability requires an electron temperature gradient and either curvature or cross-field transport
- derived using the Braginskii fluid equations in RFP geometry
- unstable only for a range of curvature around $\omega_c \sim \omega_{*p}$



γ/ω_{*p} vs. ω_c/ω_{*p}

$f = \omega_{*T}/\omega_{*p}$

Gyrokinetics and the GYRO[1] code

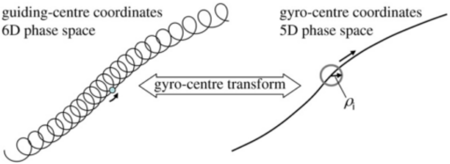


Figure 2. By applying the gyro-centre transform, fast gyro-motion is eliminated, and the problem is reduced from 6D to 5D while keeping kinetic effects such as the finite Larmor radius effect.

Garbet et al., 2010

- Kinetic equation reduced to 5D by averaging over the gyrophase angle.
- GYRO solves the gyrokinetic-Maxwell system of equations

Features of GYRO simulations

- field aligned coordinates
- linear
- local (flux-tube)
- initial value

[1] J. Candy and R.E. Waltz, Journal of Computational Physics (2003)

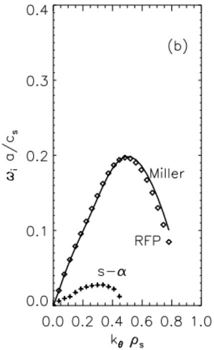
Toroidal Bessel Function Model[2]

$$B_\theta(r) = B_0 J_1\left(\frac{2\Theta r}{a}\right)\frac{1}{1+(r/R_0)cos(\theta)}$$
$$B_\phi(r) = B_0 J_0\left(\frac{2\Theta r}{a}\right)\frac{1}{1+(r/R_0)cos(\theta)}$$
$$\Theta = \frac{\langle B_\theta\rangle^{wall}}{\langle B_\phi\rangle^{vol}}, \text{ pinch parameter}$$

Modifications to GYRO are primarily due to geometric changes in operators - curvature, diamagnetic, parallel transit

$$\hat{b}\cdot\nabla = \frac{1}{qR_0}\frac{\partial}{\partial\theta} \to z\frac{1}{qR_0}\frac{\partial}{\partial\theta}$$
$$z = \frac{1}{\sqrt{1+(\frac{\epsilon}{q})^{1/2}}}$$

s-α equilibrium not adequate to describe RFP growth rates



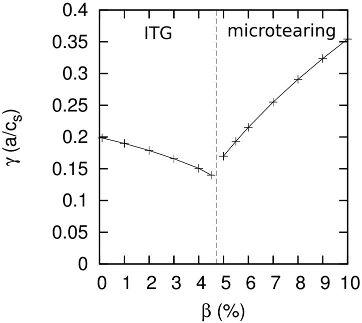
[2] V. Tangri, P.W. Terry, and R.E. Waltz (2011)

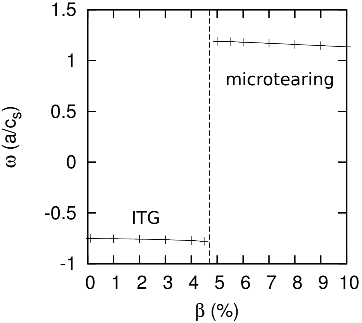
RFP Results - β_e stabilizes ITG, destabilizes microtearing

$$k_\theta \rho_s = 0.372$$

$$r/a = 0.5,\ T_e/T_i = 2.5, a/L_n = 0.58, a/L_T = 5.0, \Theta = 1.35$$

These parameters model conditions in the Madison Symmetric Torus RFP

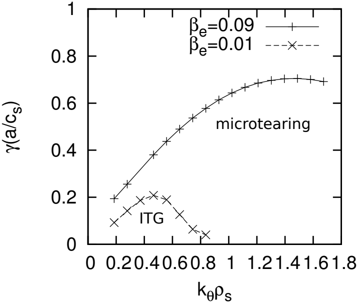


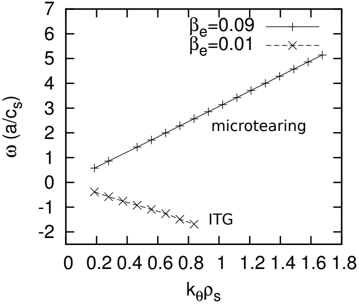


A transition of the dominant instability from ITG to microtearing occurs for $\beta_e \sim 5\%$

Shifting peak of instability growth rate

As β_e increases, microtearing becomes the dominant mode and its peak shifts to higher values of $k_\theta \rho_s$.





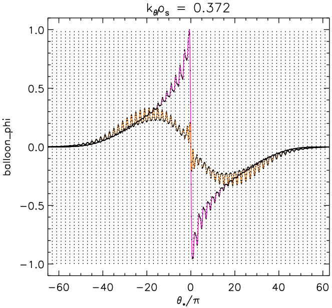
High β_e modes show microtearing eigenmode structure

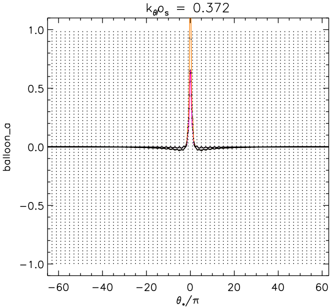
$k_\theta \rho_s = 0.372$, $\beta_e = 0.09$

The eigenmode structure at high beta shows tearing parity.

Electrostatic potential ϕ shows odd parity

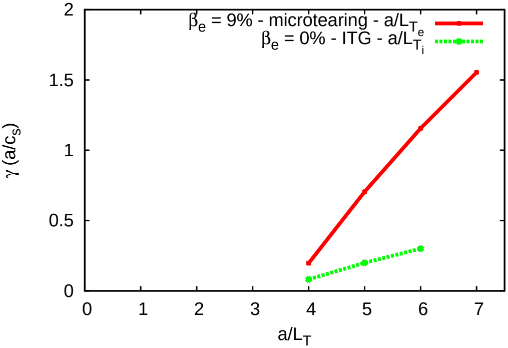
Magnetic vector potential $A_\parallel$ shows even parity





Fields are plotted against ballooning parameter θ_*

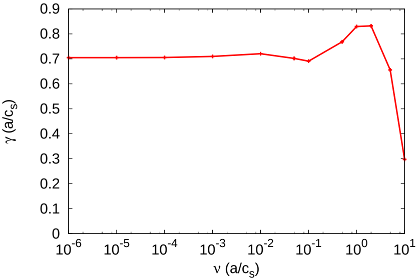
Driven by electron temperature gradient

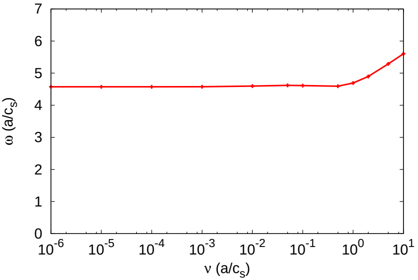


ITG and microtearing have similar gradient thresholds for instability, $a/L_T \sim 3.5 - 4$. Microtearing rises much more steeply, which is expected to lead to profile stiffness.

Role of collisions in instability

There is a peak in the growth rate near $\nu \sim 1$, but a plateau region in the low collisionality limit. This is not explained by either the thermal force or trapped particle drives.



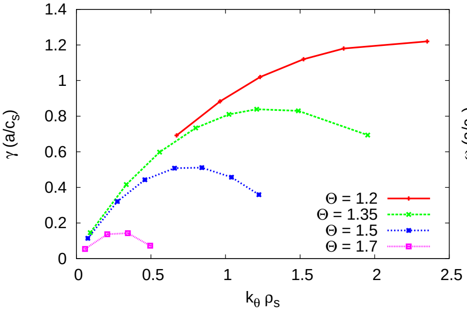


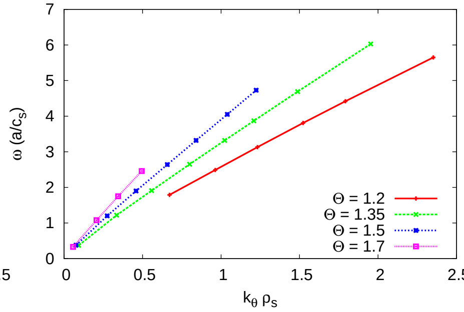
Standard discharges in MST have $\nu(a/c_s) \sim 0.15$

PPCD discharges have $\nu(a/c_s) \sim 0.01 - 0.03$

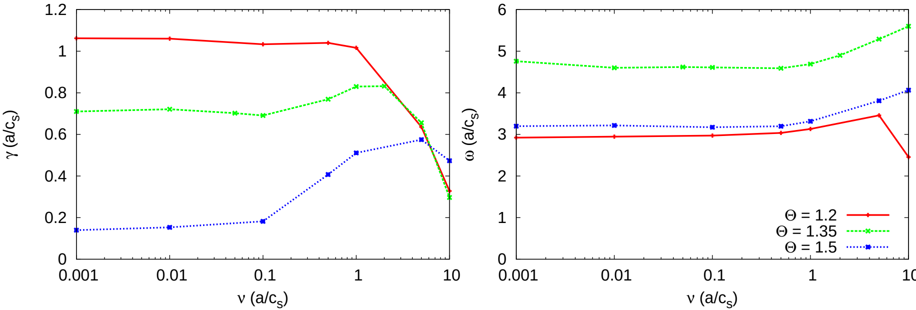
Growth rates decrease with increasing RFP Theta

$$\Theta = 1.2 : q = 0.224, s = -0.507$$
$$\Theta = 1.35 : q = 0.186, s = -0.716$$
$$\Theta = 1.5 : q = 0.153, s = -1.011$$
$$\Theta = 1.7 : q = 0.115, s = -1.637$$





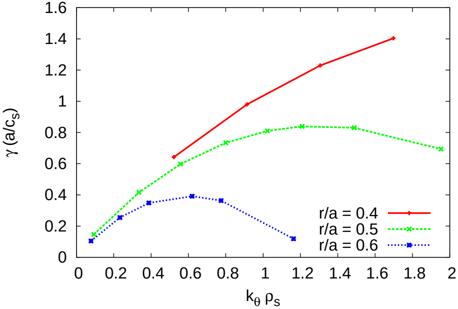
Collisionality and RFP Theta

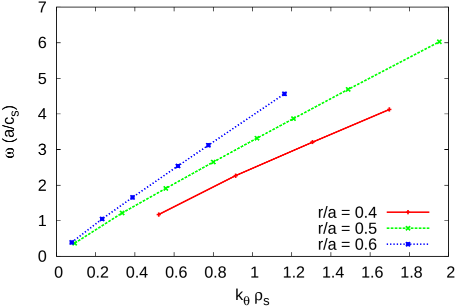


There is a different response to variation of Θ at low and moderate collisionality. This may suggest two different microtearing branches.

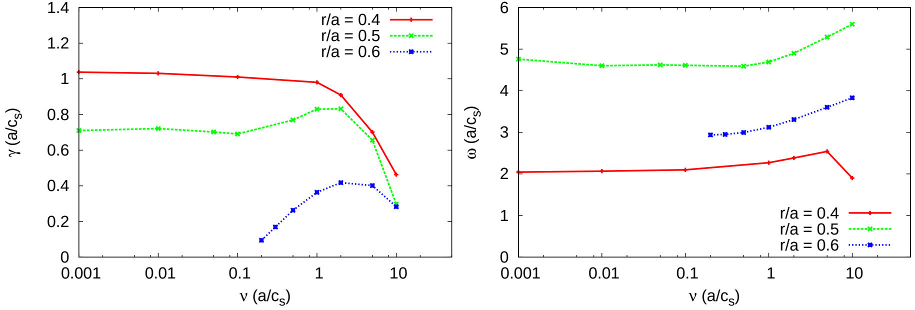
Growth rates decrease with increasing radius

r/a=0.4: q=0.209, s=-0.382
r/a=0.5: q=0.186, s=-0.716
r/a=0.6: q=0.155, s=-1.344



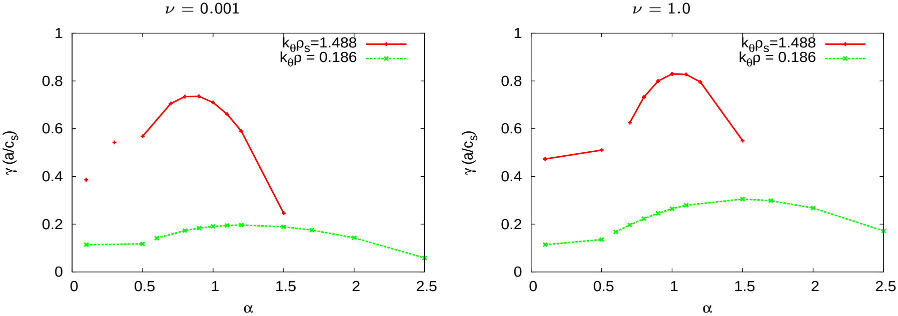


Collisionality and Radius



At $r/a = 0.4$, the strongest growth can be found in the low collision plateau region. As r increases this region is stablized more than at $\nu \sim 1$. At $r/a = 0.6$ the mode is unstable only at moderate collisionality.

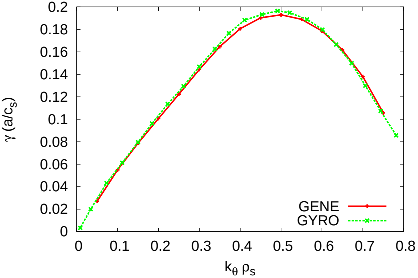
Curvature drift plays an important role in destabilizing microtearing



The parameter α is a factor multiplying the curvature drift. This mode is generally strongest for curvature near the physical value $(\alpha = 1)$, behavior that agrees with the magnetic curvature-drift instability predicted in Finn and Drake (1984,1986).

Outlook and Future Work

- GYRO results benchmarked with GENE in the ITG regime, using GENE's circular equilibrium with modifications to dB/dr
- Preliminary work with experimental profiles suggests:
  - Standard discharges stable to microinstabilities
  - PPCD disharges stable within reversal surface, unstable outside



Summary

- Microtearing modes arise across a variety of parameter regimes in the RFP
- Growth rates vary with radius and the RFP pinch parameter in a way that indicates there may be separate microtearing branches at low and moderate collisionality.
- Stabilization is correlated with local shear
- Strength of growth rate in collisionless regime suggests mechanism is different from thermal force or trapped particle drive
- Curvature drift plays an important role in instability in both the collisionless and moderate collisionality regimes and may be described by the magnetic curvature-drift instability in Finn and Drake (1984,1986)
- These results may be relevant for the spherical tokamak and other devices with curvature drifts much stronger than conventional tokamaks