Progress in Gyrokinetic Simulations of Microtearing Turbulence

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A brief history of microtearing research

- **1968**: **Tearing** instability (Furth, Killeen, Rosenbluth)
- **1975**: Instability due to $\nabla \mathbf{T_e}$: μ-tearing (Hazeltine et al.)
- **1980**: Model for **saturation** (Drake et al.)
- **1990**: μ-tearing should be **stable** for realistic tokamak scenarios (Connor et al.)
- **1999**: Focus on μ-tearing in **plasma edge** (Kesner et al.)
- **2003**: Linear **gyrokinetic simulations** (Redi et al., Applegate et al.); Large electron heat transport in **spherical tokamaks** caused by μ-tearing?
- **2008**: μ-tearing modes also found in **conventional tokamaks** (linear GK, Vermare et al., Told et al.)

Scope of this work

Problems

- **Existence** of microtearing instability in Tokamak geometry
- Electromagnetic **heat transport** caused by microtearing
- **Nonlinar saturation** of microtearing turbulence

Strategy

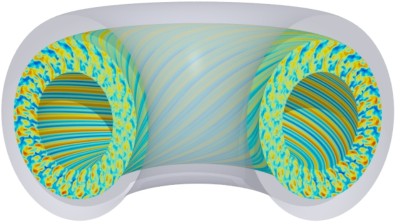
- Linear and nonlinear **simulations** using GENE
- Examine impact of steeper gradients, collisional effects...
- Comparison to **analytical models**

The GENE code

Gyrokinetic Electromagnetic Numerical Experiment

Solves gyrokinetic equations on fixed grid in 5D phase space
(⇒continuum code)

- Comprehensive physics
- Massively parallel
- Open source

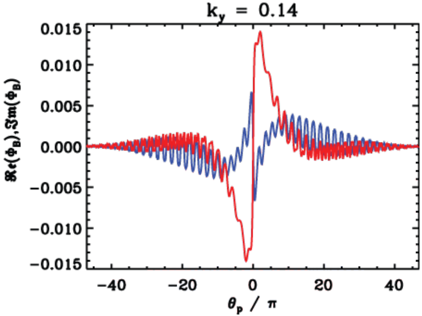


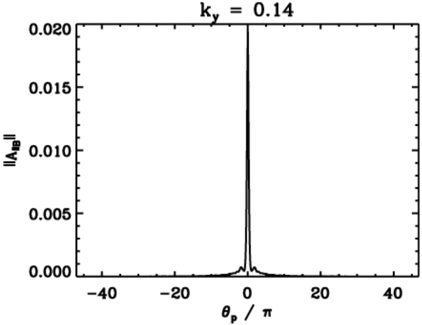
http://www.ipp.mpg.de/∼fsj/gene/

Characteristics of μ-tearing modes

Ballooning representation

- Fluctuating **electrostatic potential** $\tilde{\phi}$ extends along field line
- **Vector potential** $\tilde{A}_{||}$ is strongly localized around $\theta = 0$



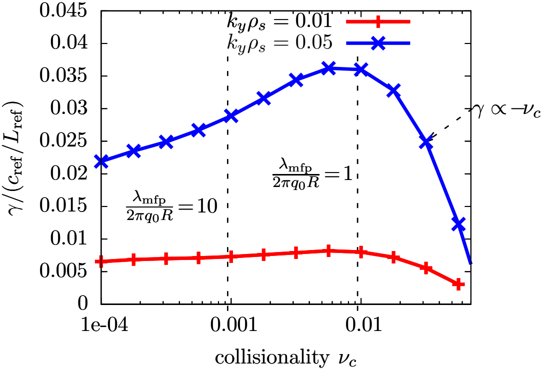


μ-tearing modes found in

- Spherical tokamaks (NSTX, MAST)
- Conventional tokamaks (ASDEX Upgrade)
- Model geometry: *Circular* (Lapillonne et al. 2009)

Influence of collisions

- Growth rate depends on collisionality ν_c only moderately
- Agreement with Applegate 2007



Microtearing modes exist in the weakly collisional regime!

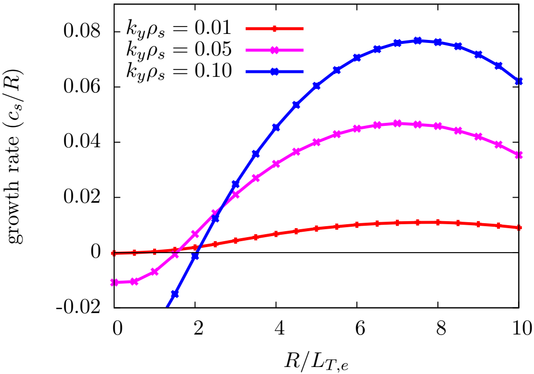
Influence of temperature gradients

Ions

- R/L_{T_i} not important

Electrons

- $\frac{R}{L_{T_e}} = -\frac{R}{T_e}\frac{\partial T_e}{\partial x}$ crucial
- $\left(\frac{R}{L_{T_e}}\right)_{\mathrm{crit}} \sim 1.5$



Existence of a critical electron temperature gradient confirmed

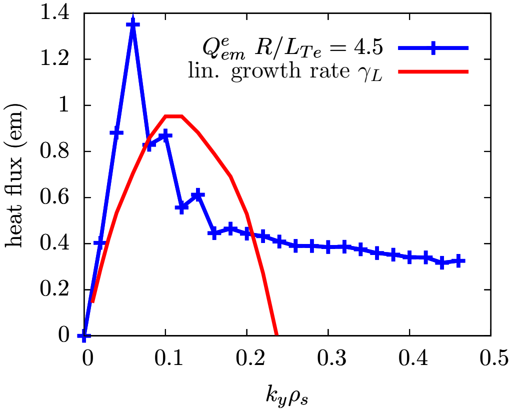
Microtearing Turbulence Spectrum

Nonlinear

- Peak at low k_y
- Extends to large k_y

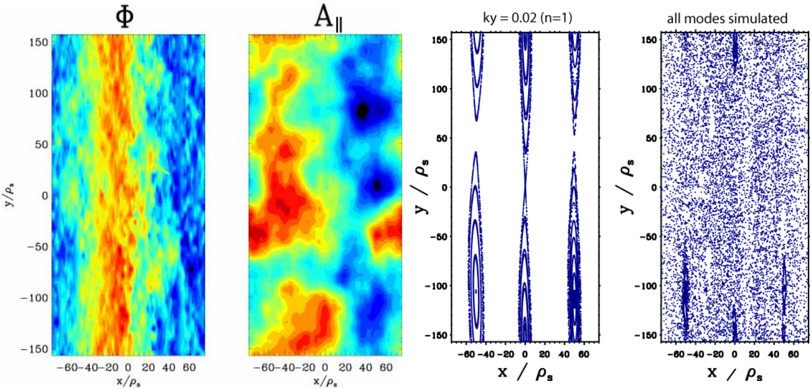
Requirements

- Large box
- High radial resolution



Nonlinear microtearing simulations are challenging to perform

Magnetic Field Stochastization



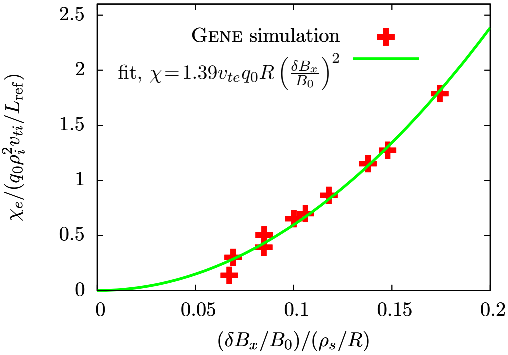
Magnetic field fluctuations of microtearing turbulence leads to field stochastization

Heat Transport in Stochastic Magnetic Fields

$$\chi_e^{em} = v_{te} D_M$$

$$D_M = L_0 \left(\frac{\delta B}{B_0} \right)^2$$

- Collisionless case $L_0 = q_0 R$
- Collisional case $L_0 = \lambda_{\mathrm{mfp}} = v_{te}/\nu_e$ (Wong et al., PRL 2007)

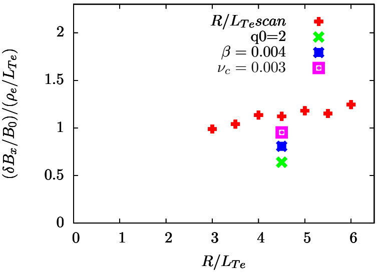


Simple model (e.g.Liever 1985) confirmed in collisionless case

Nonlinear Behavior of Microtearing Turbulence

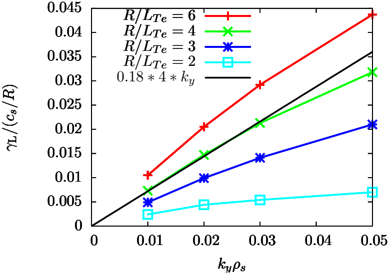
Model by Drake '80

- $\gamma_{\mathrm{L}} \sim v_{te}\lambda_{\mathrm{mfp}} \left(\varrho_e/L_{Te}\right)^2 k_\perp^2$
- $\gamma_{\mathrm{NL}} \sim -D_M k_\perp^2$
- $\Rightarrow \delta B/B_0 \sim \varrho_e/L_{Te}$



Gyrokinetic simulations

- Relevant low k regime: $\gamma_{\mathrm{L}} \sim 0.18\frac{R}{L_{Te}}k_y$
- Robust to changes in β, ν_c, (R/L_n), q_0, $\hat{s}$

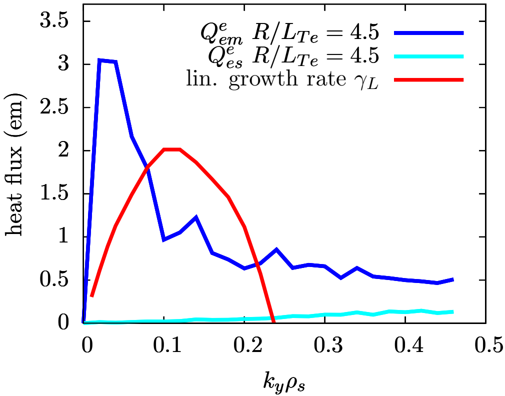


Nonlinear saturation mechanism is an open issue

Problems of Microtearing Simulation

sometimes...

- Peak at lowest k_y
- No saturation of heat flux



Solution

- Larger box?
- Higher resolution?
- Some Physics missing?

Nonlinear microtearing simulations are very challenging to perform

Conclusions

- Microtearing modes can be unstable in conventional tokamaks
- **Heat transport** can be substantial
- Nonlinear **saturation mechanism** is an open issue
- Further simulations:
  System size: global
  microtearing + ITG
  . . .

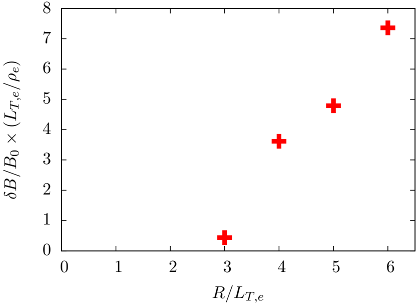
Microtearing modes may play a role in future tokamak experiments like ITER

Thank you for your attention!

Nonlinear results adiabatic ions

Magnetic fluctuations

- Magnitude $\delta B/B_0 \times (L_{T_e}/\varrho_e) \sim 1$ (Drake)
- **Stronger scaling** with R/L_{T_e}



Heat diffusivity

- Rapidly increases with R/L_{T_e}
- Nonlinear upshift of the **Critical gradient** $(R/L_{T_e})_{\rm crit}$