The scaling of micro-turbulence in Reversed Field Pinch Plasmas

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52nd Annual APS DPP, Chicago, Nov, 2010
Motivation

ITG may be unstable in RFPs!

- It has been known that RFP temperature profiles are quite steep esp. close to reversal radius.
- In MST, $R/L_{Ti} > R/L_{Ti, crit}$[slab]
- In RFX $R/L_{ti} \sim R/L_{Ti, crit}$
- RFX: extremely flat density profile while the ion temperature profile is found to be peaked.
  [Carraro et al. 1993]

Fine, but hasn’t micro-instability driven transport been studied before?
YES

- Gladd CD-drift wave 80’s
- Terry 1990 resistive g-mode
- [Guo (1997) fluid approximation, strong ballooning, neglected landau damping ; Guo (2008) only retain curvature drift and not gradient drift, and use the fluid approximation. ]
- Predebon (2010) studies Gyrokinetic simulations for RFX
- Sattin (2010), Liu 2010
Studies of modes responsible for turbulent transport can be done in a number of ways, some of which are....

a) Develop equilibrium approximations to standardize parameters for studies with gyrokinetic simulations.

b) Benchmark with existing equilibria e.g. Miller and $s-\alpha$

c) Studying simulations for various parameters may help resolve this.
Toroidal Bessel function model is toroidal generalization of Bessel function model

From Grad-Shafranov solution:

**Shifted circle equilibrium**

\[
B_\phi = \frac{B_0 J_0(2r\Theta/a)}{1 + \epsilon (r/a) \cos \theta},
\]

- Shift can occur for $\beta = 0$
- Shift important for $\Theta$ large

\[
B_\theta = \frac{B_0 J_1(2r\Theta/a)}{1 + \epsilon \left(\frac{r}{r + \Delta'}\right) \cos \theta},
\]

Toroidal Bessel function model:

\[
B_\phi = \frac{B_0 J_0(2r\Theta/a)}{1 + (r/R_0) \cos \theta},
\]

- Neglects shift
- Valid for $\Theta < 3$

\[
B_\theta = \frac{B_0 J_1(2r\Theta/a)}{1 + (r/R_0) \cos \theta},
\]

- Both field components have $1/R$ factor with poloidal variation

Once $\Theta$ and $r$ are specified, parameters including $s$, $q$ are known as well
(b)

The Three Geometries: Comparison

\( r/a = 0.5 \)
RFP geometry is more important near the reversal radius

- The variation of growth rate was studied for the fixed values of the parameters:
  \[
  \frac{a}{L_n} = 0.58 \\
  \frac{a}{L_T} = 5 \\
  \Theta = 1.35
  \]
  The parameters were chosen such that the growth rate close to reversal radius still significant.

- The range of \( k_\theta \) with significant growth rate decreases.

- The growth rate decreases as we vary the radial location. It is very small near the reversal radius.

- The deviation from miller model also increases.
High pinch parameter is stabilizing

At low $\Theta$, (~1.55), where shear is nearly zero, the growth rate is comparable to the perpendicular ion thermal transit time ($a/c_s$).

At high pinch parameter $\Theta$ (which implies high negative shear and low $q$), ITG modes are stabilized.
Steeper temperature gradient means higher growth rate

- Normalized Temperature gradient length \([a/L_{Ti}]\) varied from 5.0-11.
- Growth rate increases with increasing \(a/L_{Ti}\)
(c)

increasing Ti/Te reduces transport

- Ti/Te varied in the range 0.2-1.4
- hotter ions lead to lower linear growth rate
(c) Turbulence varies with scale

- The effect of non-adiabatic ions on the ITG instability in a RFP geometry has also been investigated.

- TEM growth rate larger than ITG.

- The direction of propagation depends on scale.

- Nonlinear interaction is expected to be important.

- Trapped Electron effects may be important.
ITG threshold and Dimits shift

- Preliminary non-linear simulations are presented.
- We have studied the Dimits shift.
- Threshold in RFP is $R/a$ times larger

[For linear simulations, the fastest growing mode is chosen.]

[For Nonlinear simulations, the mode amplitude is used.]
Summary & Conclusions

(a) Develop

• We propose use of standardized an equilibria for studies with gyrokinetic simulations.
• The code GYRO has been modified to incorporate a consistent equilibrium.

(b) Compare

• compared with the standard models i.e. Miller and and s-alpha.
• Results diverge from the tokamak miller model near the reversal radius. The new effects are found stabilizing! We have performed Linear and nonlinear simulations using this model.

(c) Parameterize

• For sufficiently high temperature gradients, ITG has been found unstable in the RFP.
• Ti/Te may have a stabilizing effect on ITG turbulence.
• Increasing the pinch parameter $\Theta$, reduces the growth rate.
• TEM branch ($k \rho_i > 1$) is also unstable and has a higher growth rate than the ITG.
• Nonlinear studies also presented, Dimits shift etc.

Thanks!