Gyrokinetic Calculations of Microinstabilities and Transport during RF H-modes on Alcator C-MOD

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Motivation

- Investigate microinstabilities and transport in CMOD ITB experiments:
  ITG, TEM, ETG
- Identify underlying key plasma parameters:
  Control of plasma performance

OUTLINE

1. Experimental Characteristics of ITB in RF off axis H-mode

2. Gyrokinetic GS2 code results consistent with χ analysis
   - **ITG mode stable in & at ITB, unstable outside ITB**
     => anomalous c_i outside ITB
   - **ETG mode unstable at and outside ITB**
     => anomalous c_e at and outside ITB
   - **TEM not strongly growing**

All CMOD ITB cases behave similarly:

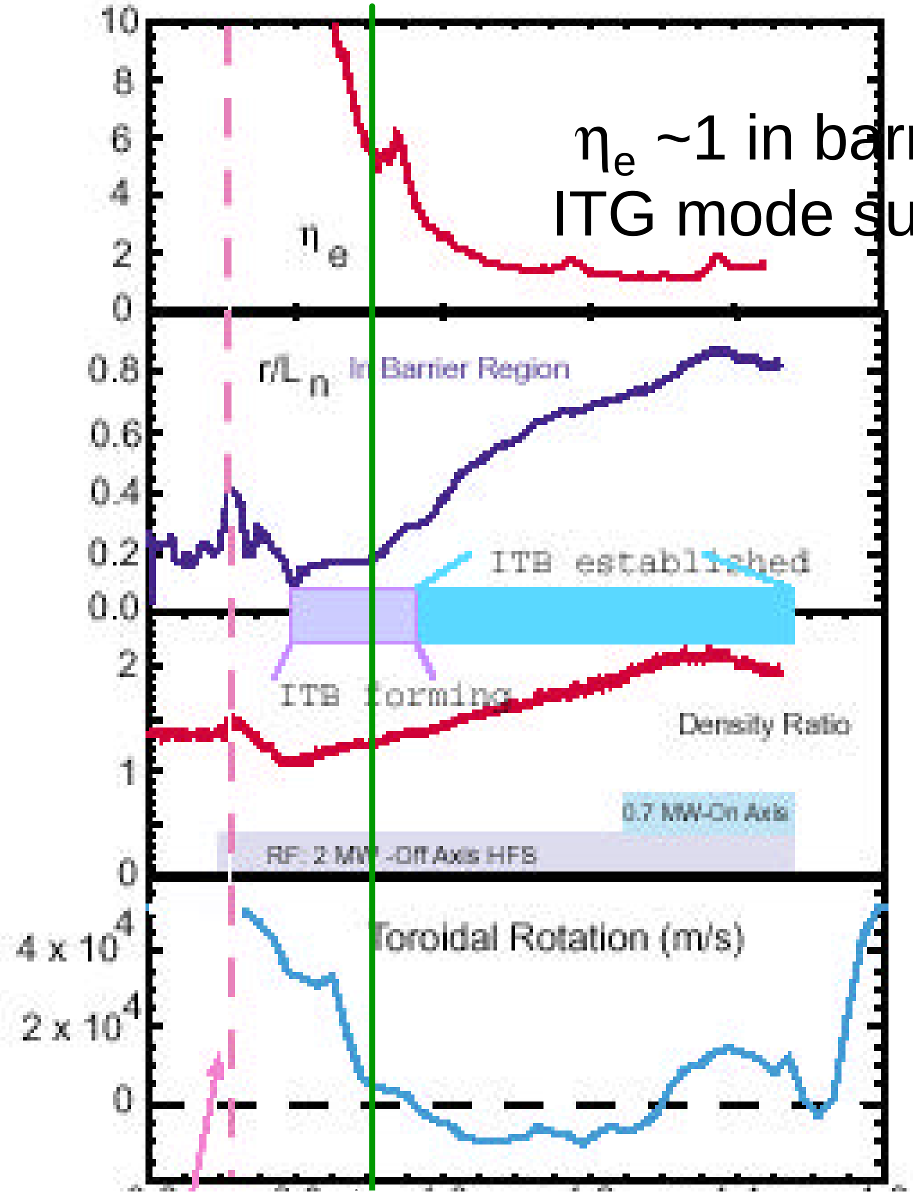
Dual Frequency RF Case

η_e approaches 1 in the barrier

R/Ln increases

The density becomes peaked

The toroidal rotation velocity decreases



η_e ~1 in barrier region
ITG mode suppressed?

FIORE-APS 2001

Experimental Characteristics of ITB

- *Reduction in particle transport is evident*
  in the peaked density profile without a central particle source

- *Maintaining the central temperature*
  while the central density is increasing
  suggests a thermal transport barrier

- *Transp analysis shows* c_{eff} *drops inside ITB*

- *Sawtooth heat pulse analysis*
  also shows a thermal transport barrier

- *For ICRF EDA H-mode,*
  the minority resonance is at r/a>0.5
  Normal shear profile, q monotonic.

GS2 Input: TRANSP Analysis

- TRANSP analysis is used to set initial conditions, T_e measured

  Experimental data cannot distinguish between $T_i = T_e$ *or the model used here:* $T_i \neq T_e$

  but rather consistent with $\chi_i \propto \chi_{\text{Chang-Hinton}}$
  matching the observed neutron data.

- The simulations solve the gyrokinetic Vlasov-Maxwell system,

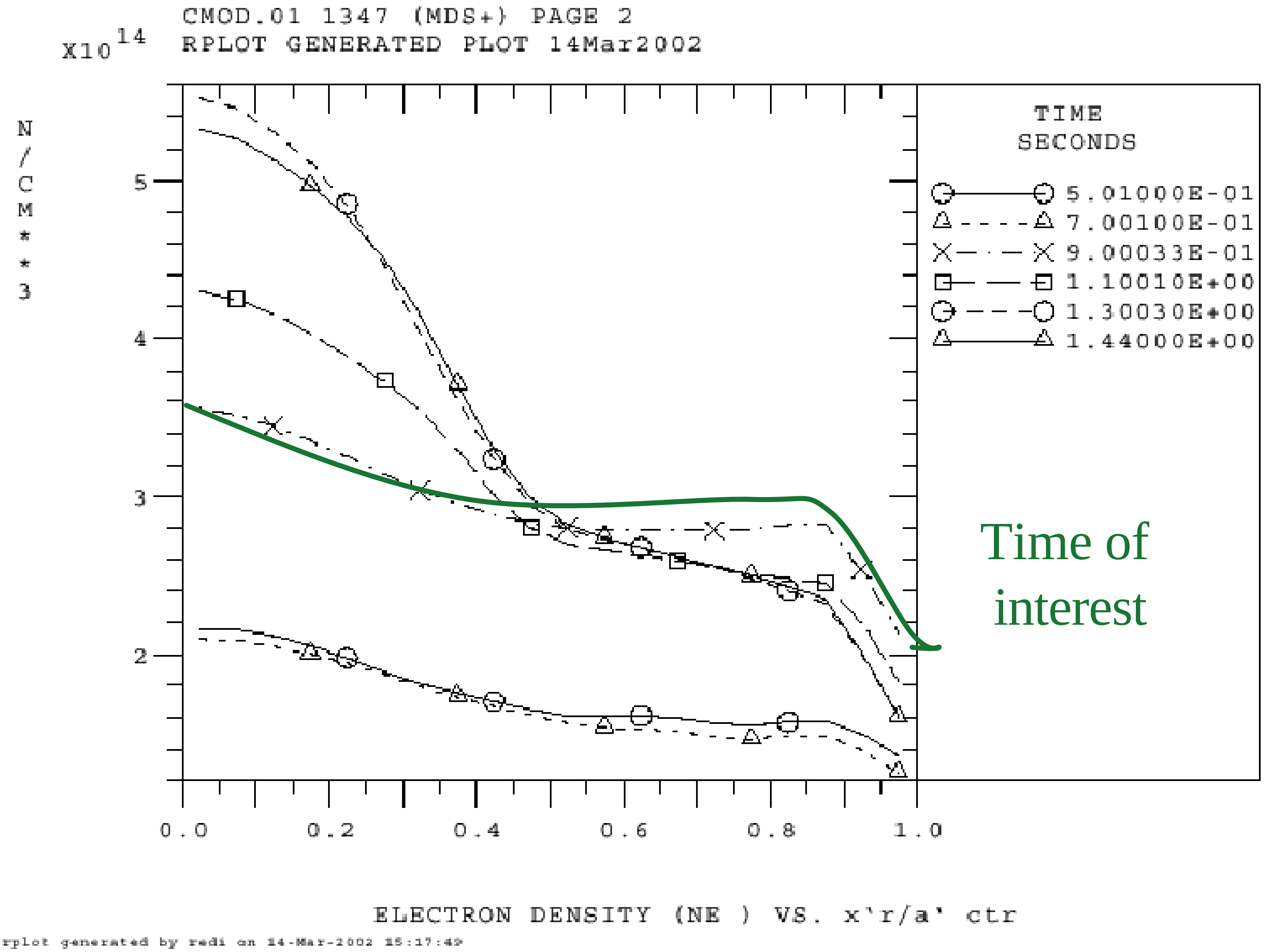
  are run out until the microinstability growth rates, g,
  and real frequencies, w, converge
  and the usual measure of the electrostatic potential $ln|f|^2$
  is linearly increasing, in cases designated unstable.

- ExB shearing rates from measurements of toroidal rotation,

  not included calculations

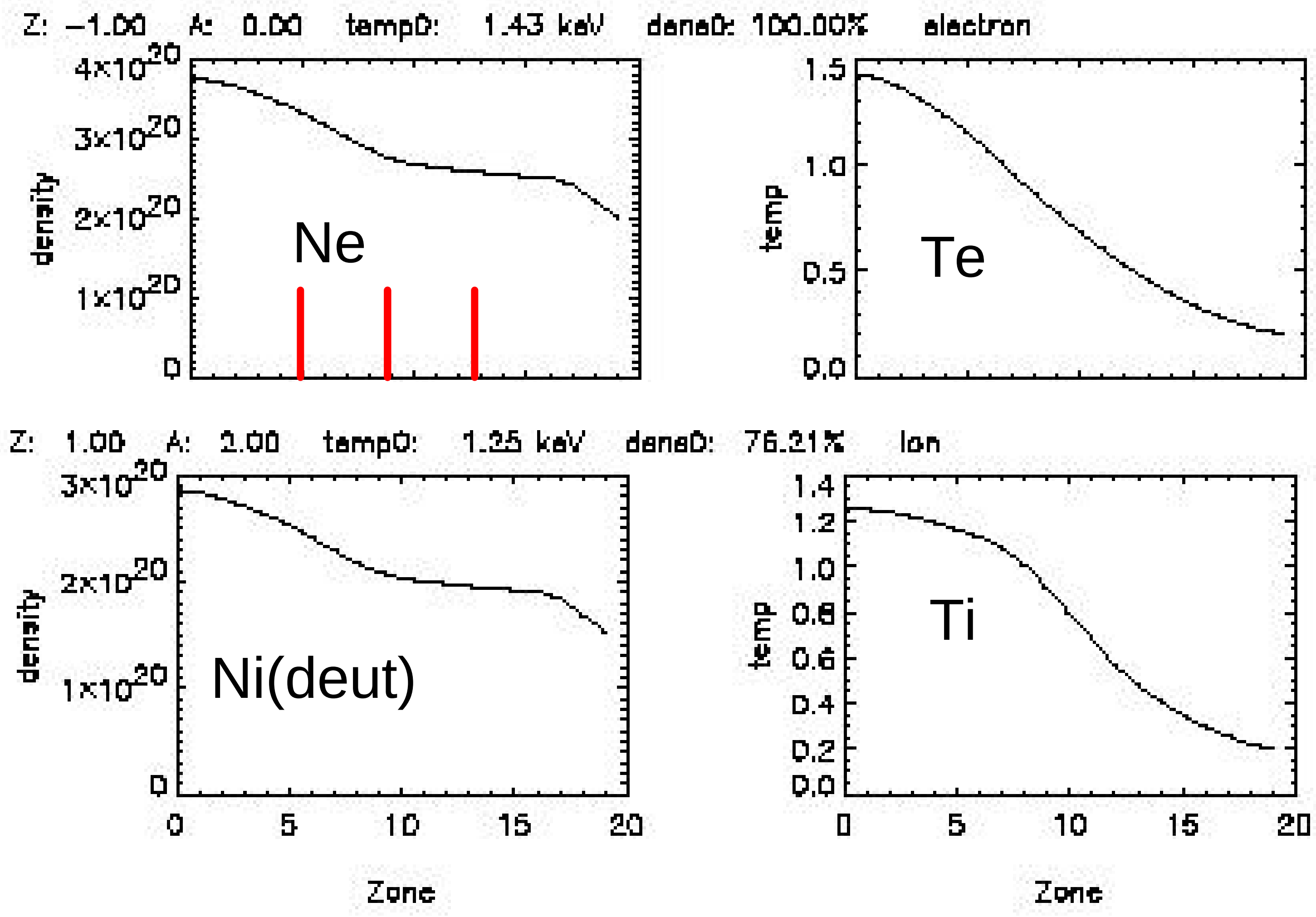
- Four species included: D, H, B, adiabatic electrons

Internal Transport Barrier in Density Profile



Time of interest

Examine Microinstability Growth Rates at 3 Zones= 5,9,13



GS2: Microturbulence at $k_\perp\rho_i$ = 0.1 to 80.

Low $k_\perp\rho_I$: ITG => $\chi_I^{anomalous}$ outside ITB

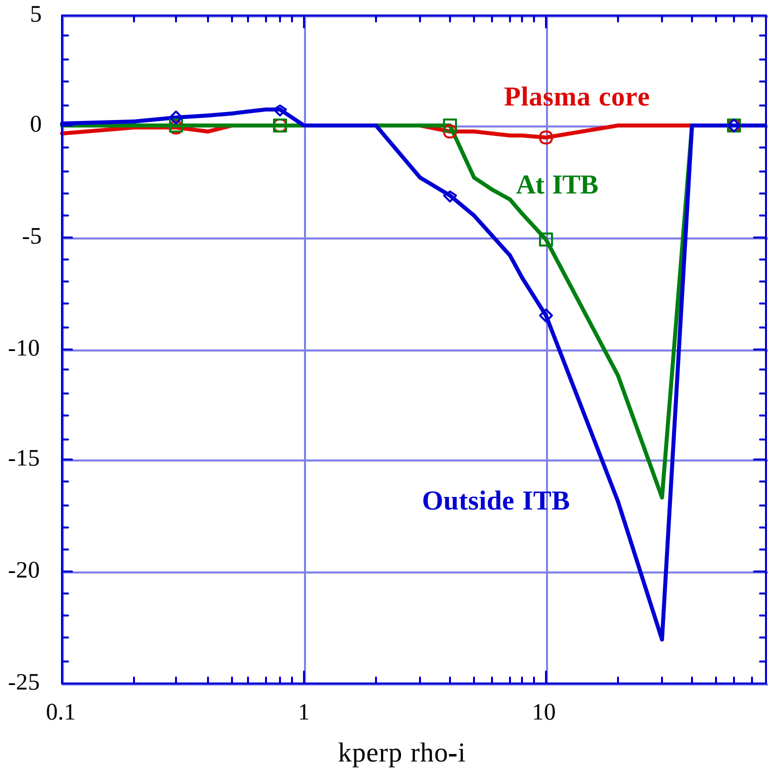
Trapped electron and η_i mode drive are weak

TEM and ITG: stabilized at and within ITB

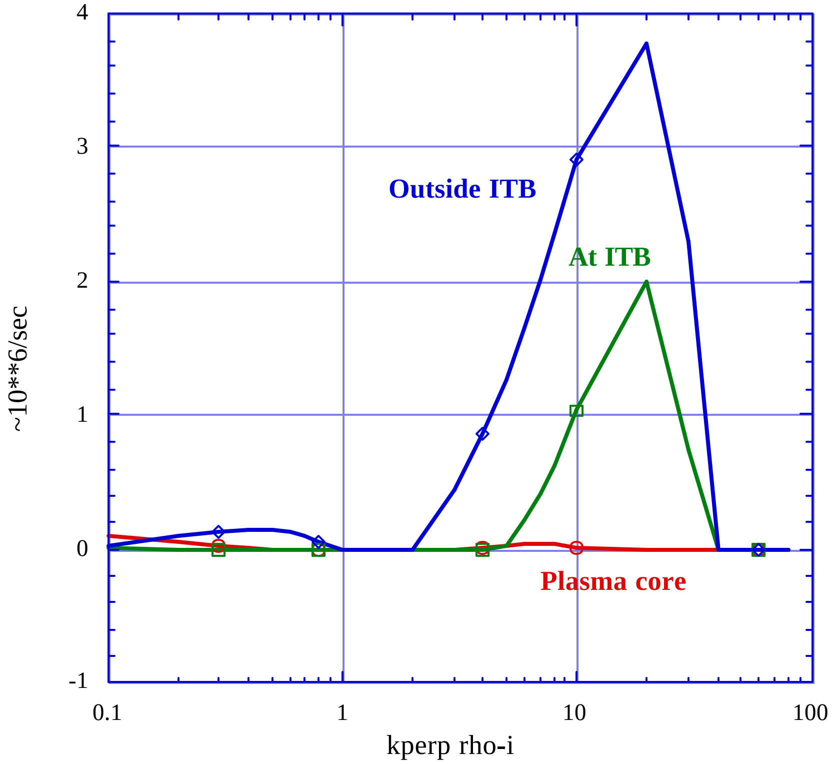
High $k_\perp\rho_i$: ETG driven by strong ∇T_e

=> $\chi_e^{anomalous}$ at and outside ITB

Real frequencies (~106/sec)**
zones 5,9,13
kperp rho-i from 0.1 through 80



Growth rates at zones 5,9,13
for kperp rho-i from 0.1 to 80
ITG stabilized in plasma core and near ITB
eta-i small, TE drive weak; ITG and TEM stable

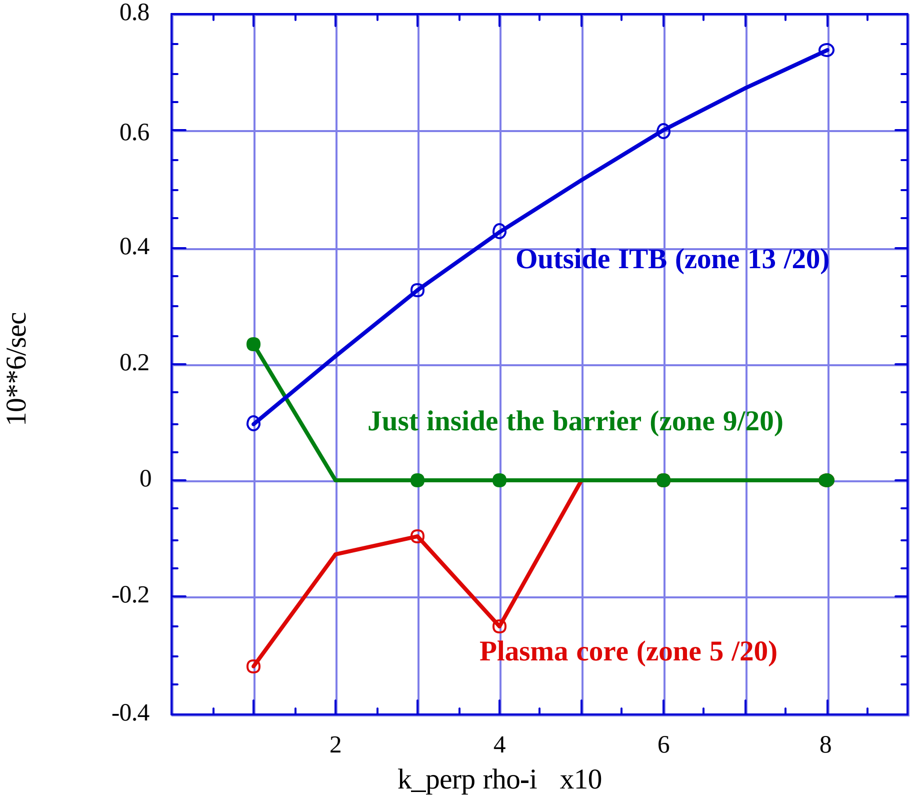


Long Wavelength Drift Modes: $k_{\perp}\rho_i = 0.1$ to 0.8

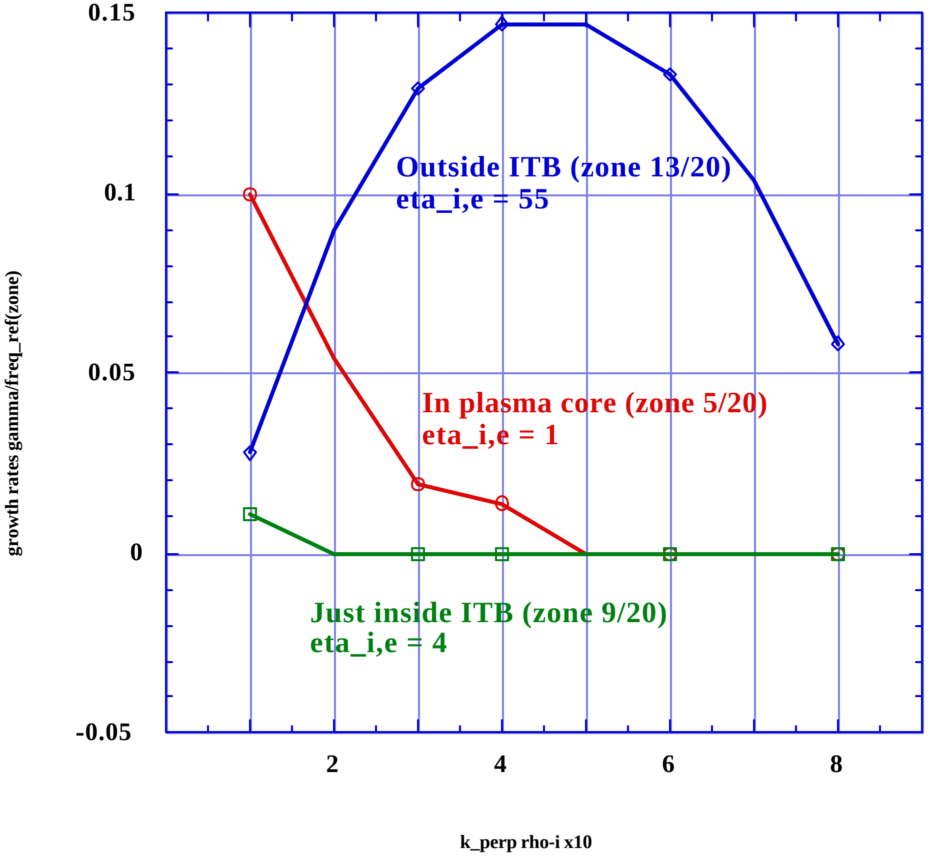
TEM: not strongly growing at & within ITB

ITG: stable at & within ITB, unstable outside ITB

Real Frequency of Dominant Drift Mode during Initial Stage of ITB Formation

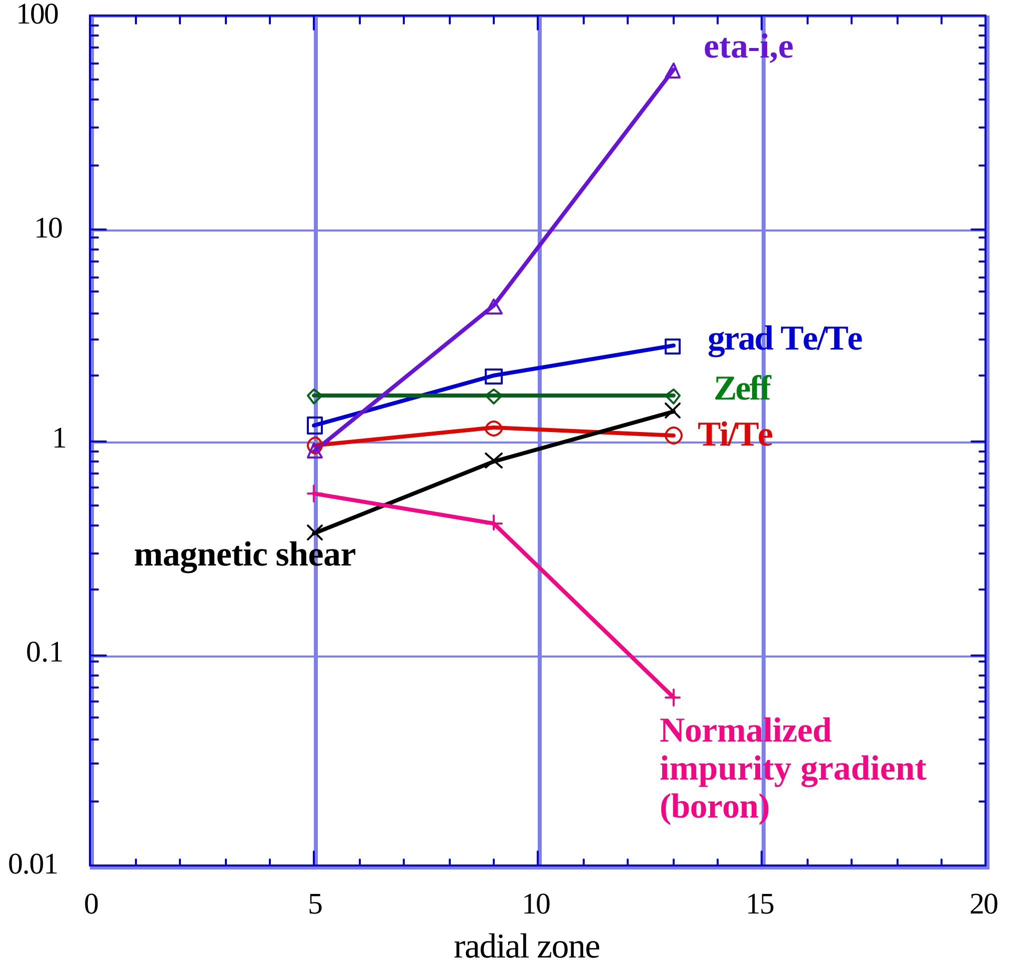


Drift Mode Microinstability Growth Rates During Initial Stage of ITB Formation



Driving Forces for Drift Modes in Off-Axis Case as ITB Is Established

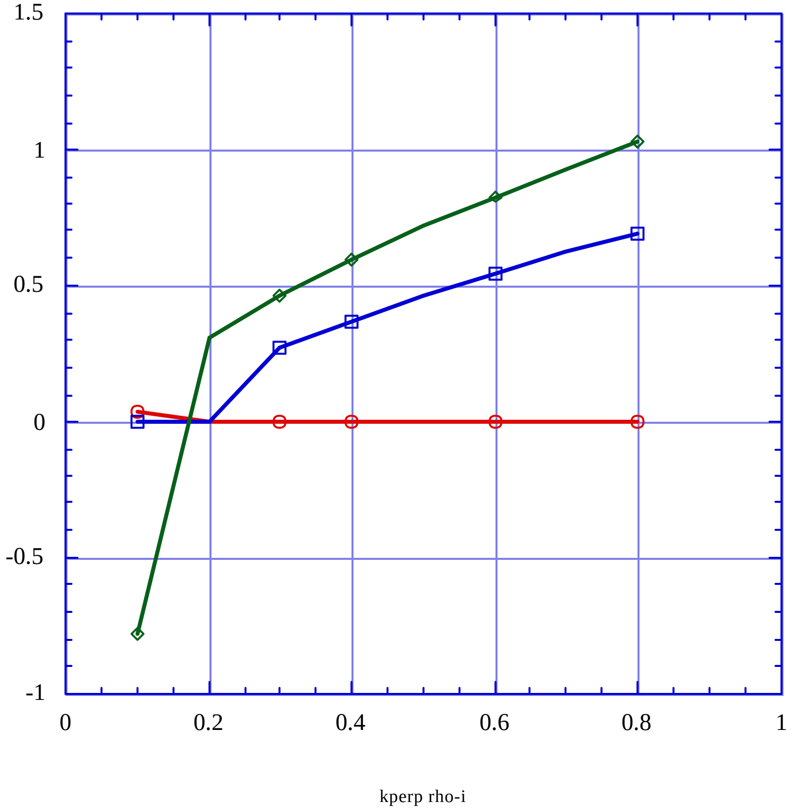
Driving forces destabilize drift mode turbulence
eta-i,gradTe,destabilize modes to outside of ITB
impurities may stabilze modes at and within ITB
magnetic shear role complex, to be tested



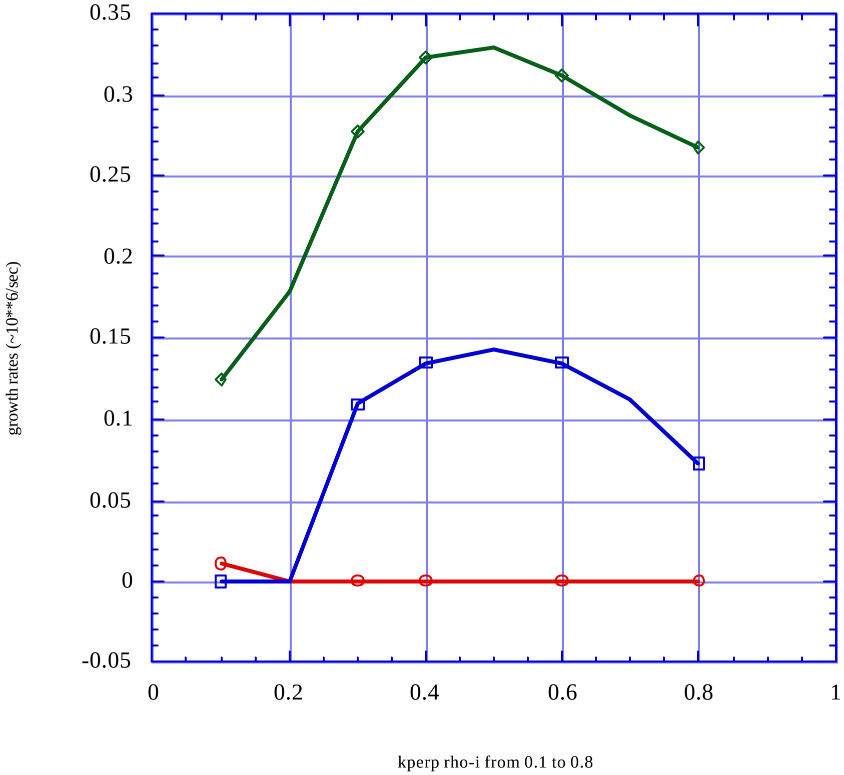
At ITB: Long Wavelength Drift Modes: $k_\perp \rho_i$ = 0.1 to 0.8
If grad Te Doubled and Quadrupled

ITG: destabilized by increase in ∇T_e

TEM: not affected



real frequencies for kperp rho- from 0.1 to 0.8
for baseline (red), gradTe x2 (blue)
and gradTe x4 (green)



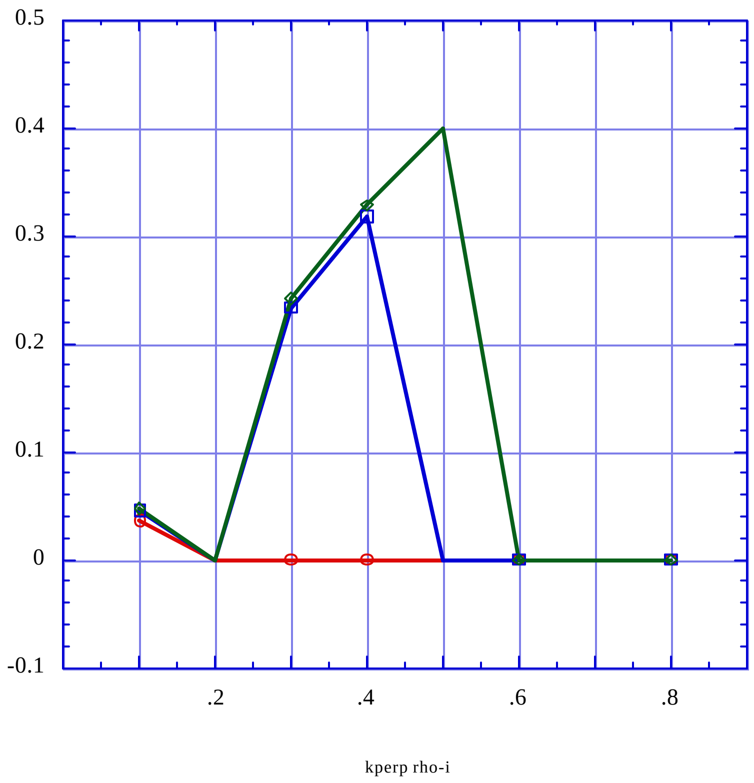
Growth rates of ITG mode (red)
destabilized at ITB (zone 9)
if grad Te is doubled (blue) or quadupled (green)

At ITB: Long Wavelength Drift Modes, $k_\perp \rho_I < 0.8$
∇n_e reduced by 1/2 and by 1/4

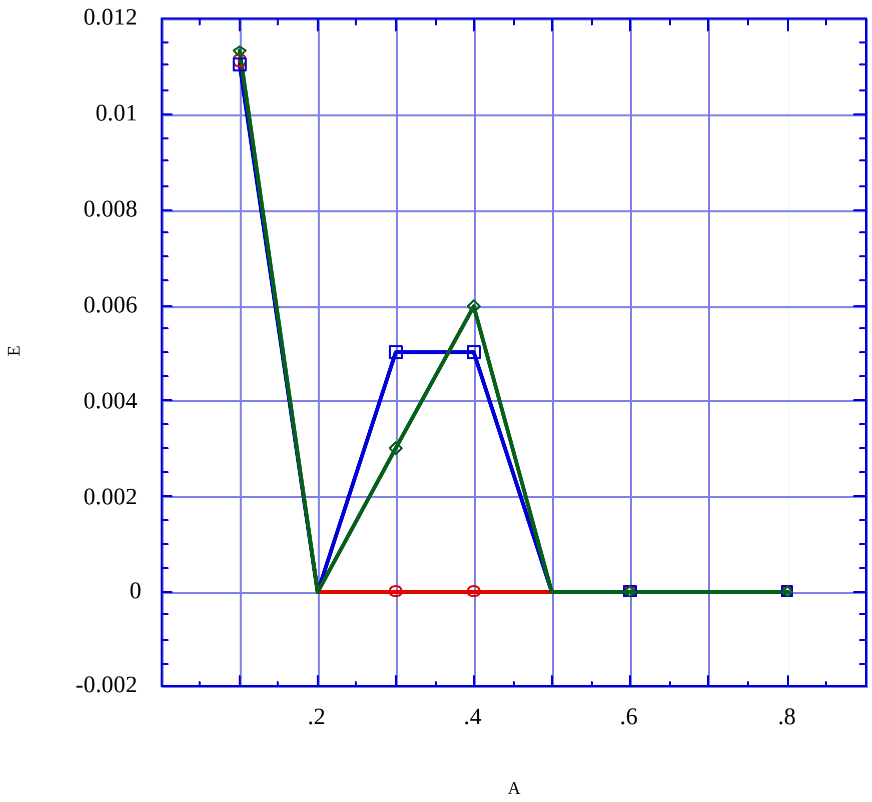
ITG: destabilized by decrease in ∇n_e

TEM not affected

At ITB (zone 9), real frequencies:
if decrease grad Ne (red) by 1/2 (blue) and by 1/4 (green)
Drift mode destabilized in ion diamagnetic direction



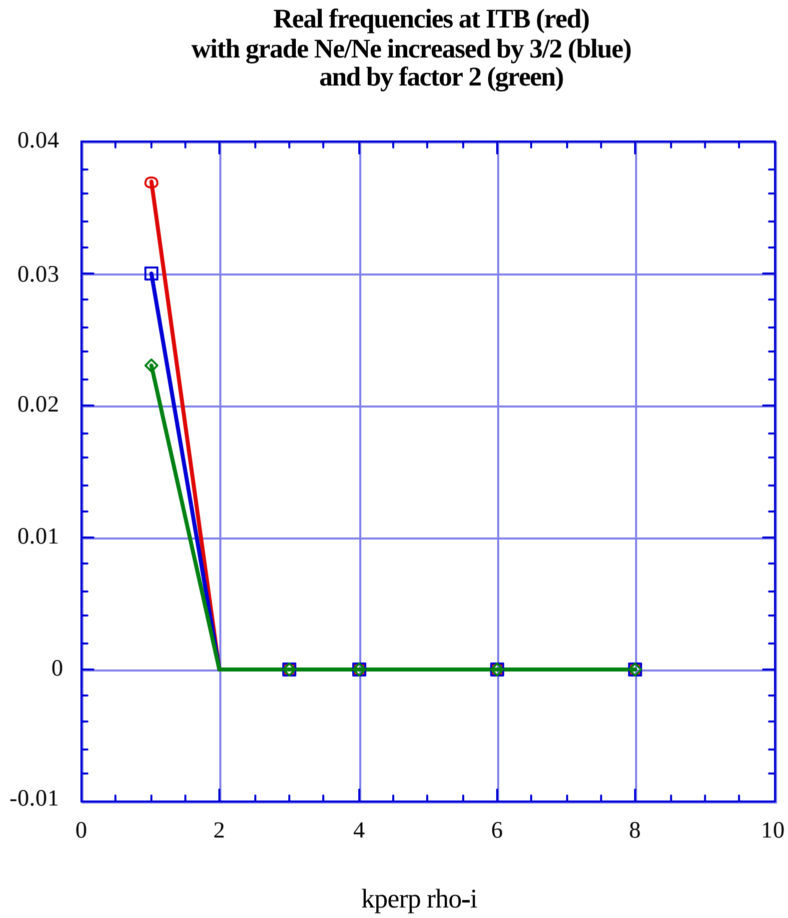
ITG destabilized if Grad Ne smaller:
Growth rates at ITB zone 9 (red)
increase if grad Ne decreased by 1/2 (blue)
or by 1/4 (green)



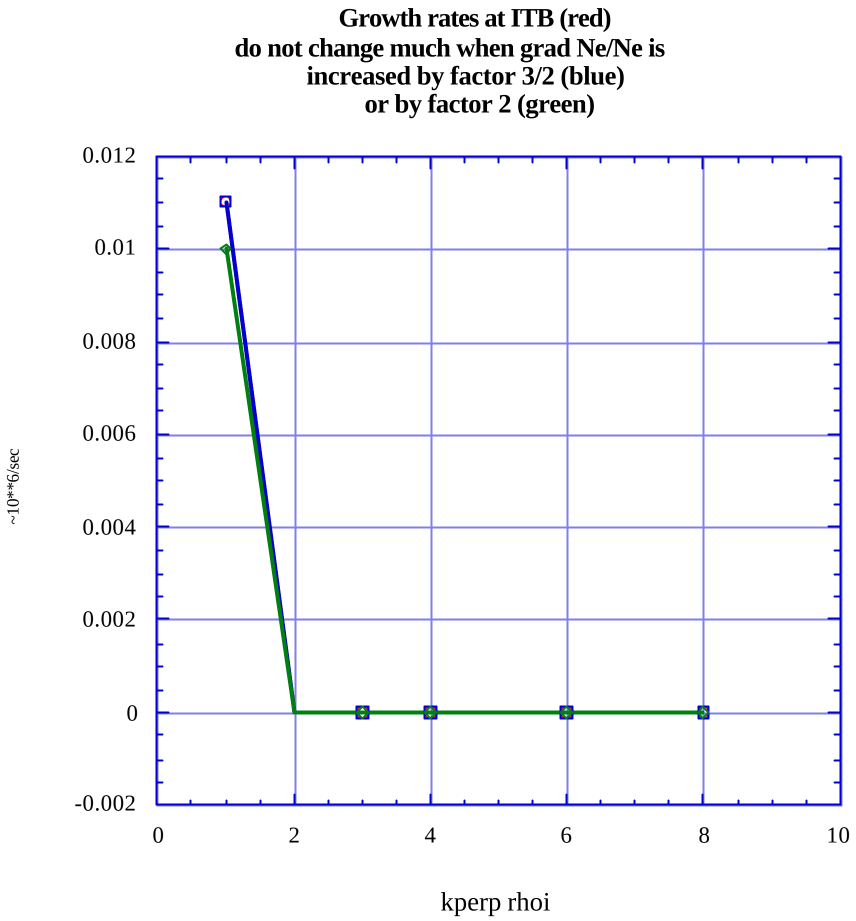
At ITB: Long Wavelength Drift Modes, $k_\perp \rho_I < 0.8$

~ No change if $\nabla n_e / n_e$ increased by 3/2 or by 2

Neither TEM nor ITG destabilized by increase in ∇n_e



Real frequencies at ITB (red) with grade Ne/Ne increased by 3/2 (blue) and by factor 2 (green)



Growth rates at ITB (red) do not change much when grad Ne/Ne is increased by factor 3/2 (blue) or by factor 2 (green)

Summary

Before n_e peaks, region of reduced transport and stable microturbulence is established (without ExB shear)

- ITG, toroidal ion temperature gradient mode
  => $\chi_I^{anomalous}$, unstable outside ITB
  stabilized at & within the ITB, η_e drops within ITB
  At ITB, stabilized by steep density profile and moderate ∇Te
- TEM not strongly growing at small $k_\perp \rho_i$
- ETG at higher values of $k_\perp \rho_I$ => $\chi_e^{anomalous}$ outside and at ITB
  Primary contribution to $\chi_?$, D: from small values of $k_\perp \rho_I$, long λ
  Expect neoclassical χ_e, χ_i in core, as found with TRANSP

Future: Nonlinear simulations

Evaluate mass and heat transport driven by modes
What triggers and sustains ITB existence - impurities,shear?
Test driving forces for these modes; complex eqns.
Need: Ti(r) and reflectometry fluctuation measurements at ITB