TRANSPORT FROM OVERLAPPING ELECTRON AND ION DRIFTWAVE INSTABILITIES

- Electron temperature gradient modes (ETG) are a likely contributor to electron thermal transport in tokamaks.
- ETG modes are naturally short wavelength modes $k_\theta \rho_i > 1$
- Since the ion response at short wavelengths is adiabatic ETG modes only produce electron thermal transport at short wavelength.
- Two mechanisms whereby ETG modes could produce transport in other channels (ion thermal, particle, and ion momentum) are explored.
  - **A non-linear transfer of fluctuation energy from short to long wavelengths.**
  - **A quasilinear non-adiabatic ion response when ETG and ITG modes are unstable in overlapping wavenumber ranges.**
- The first growthrate spectrum from a new gyro-Landau fluid model which includes the coupling between ions and electrons at all wavelengths and has both trapped and passing particles is shown.

GENERAL ATOMICS

ETG MODES IMPACT ELECTRON TEMPERATURE

- There is considerable evidence that the ETG modes impact the electron temperature profile.
- Within a transport barrier the ITG/TEM modes are predicted to to quenched. The electron thermal transport from ETG modes alone in the GLF23 model agree well with experiment [1].
- The electron temperature profile in the steepest region of the transport barrier follows the computed critical gradient for ETG modes [2].
- Strongly negative magnetic shear increases the ETG threshold and the experimental electron temperature gradient increases to match this [3].
- Even with strong central ECH heating the electron profile in the core is close to the marginal ETG profile [4].

[1] R. E. Waltz, et al., Phys. Plasmas 4, 2482 (1997).

[2] B.W. Stallard et.al., Phys. Plasmas 6, 1978 (1999).

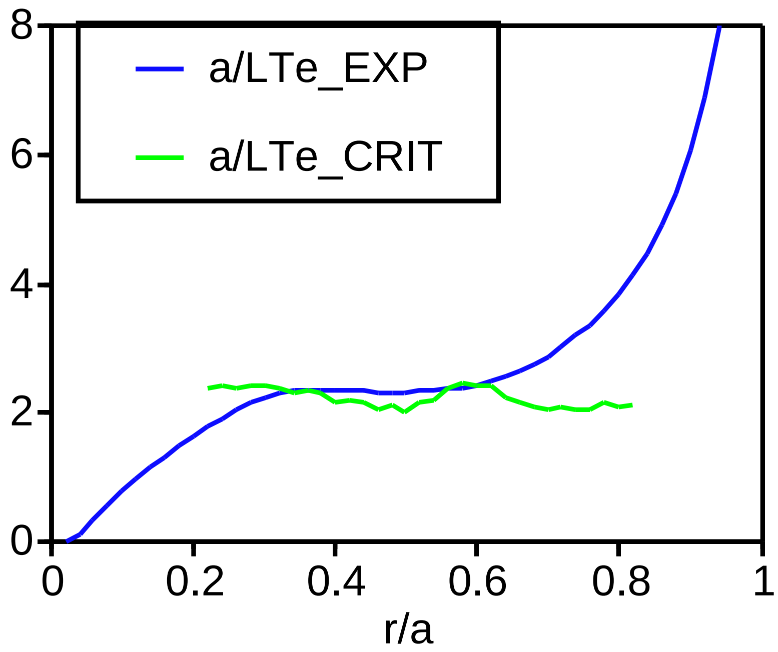
[3] C. M. Greenfield, et al., Nuclear Fusion 39, 1723 (1999)

[4] C. M. Greenfield, et al., Proc. 17th IAEA Fusion Energy Conf., Yokohama, Japan (1998)

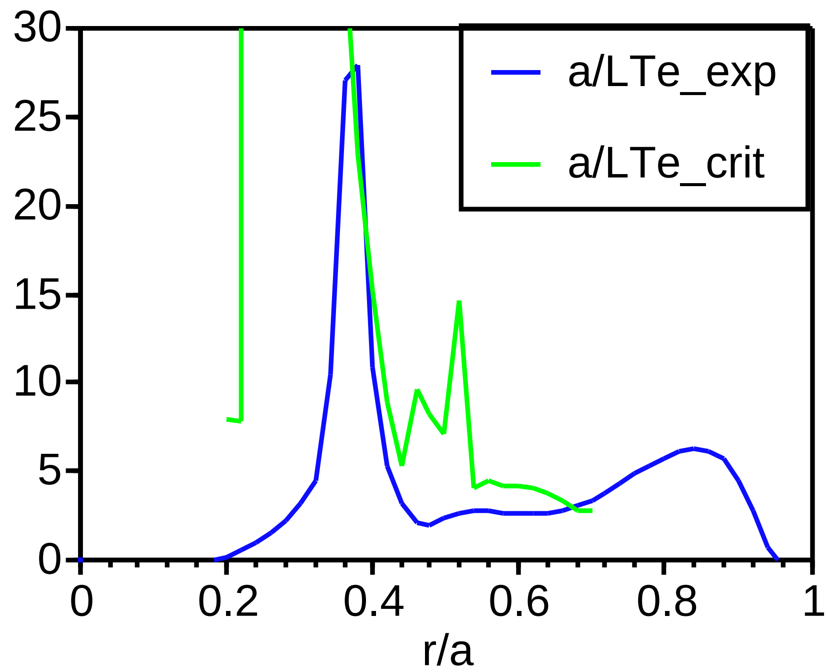
GENERAL ATOMICS

THE ELECTRON TEMPERATURE PROFILE FOLLOWS THE ETG CRITICAL GRADIENT IN THE MIDDLE CORE (0.2<R/A<0.7)

DIII-D L-mode shot 105663



DIII-D High ECH shot 99696

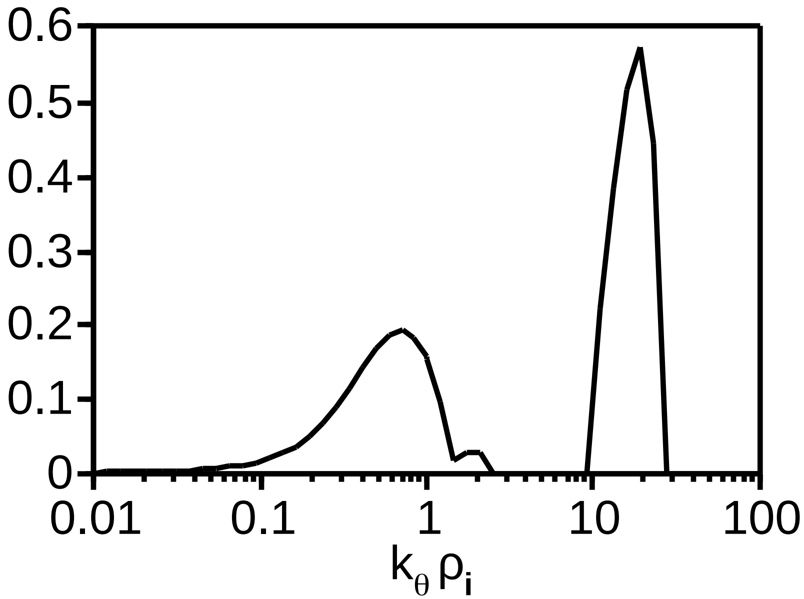


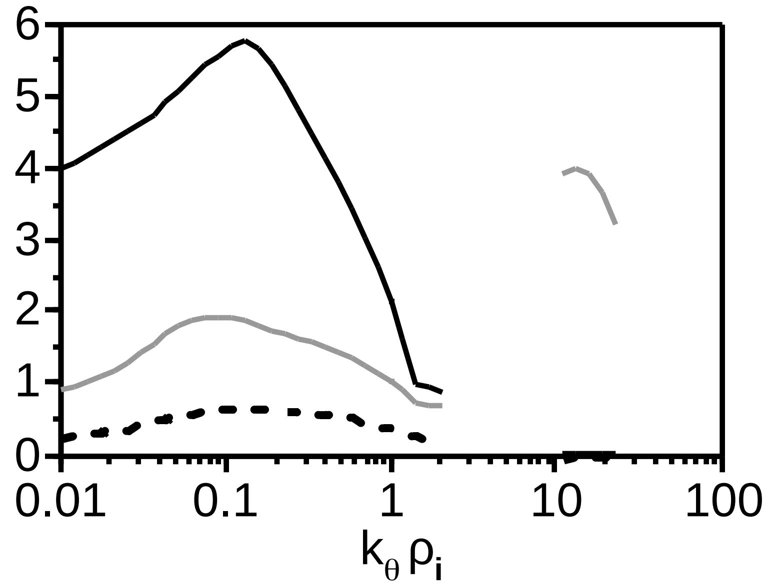
GENERAL ATOMICS

IN THE MIDDLE CORE ITG AND ETG MODES DO NOT HAVE OVERLAPPING WAVENUMBER RANGES OF INSTABILITY

Spectrum of driftwave growthrates normalized to Cs/a for DIII-D L-mode shot 105663 at r/a=0.4

Quasilinear weights for :
ion energy flux(black)
electron energy flux (grey)
Particle flux (chain)





GENERAL ATOMICS

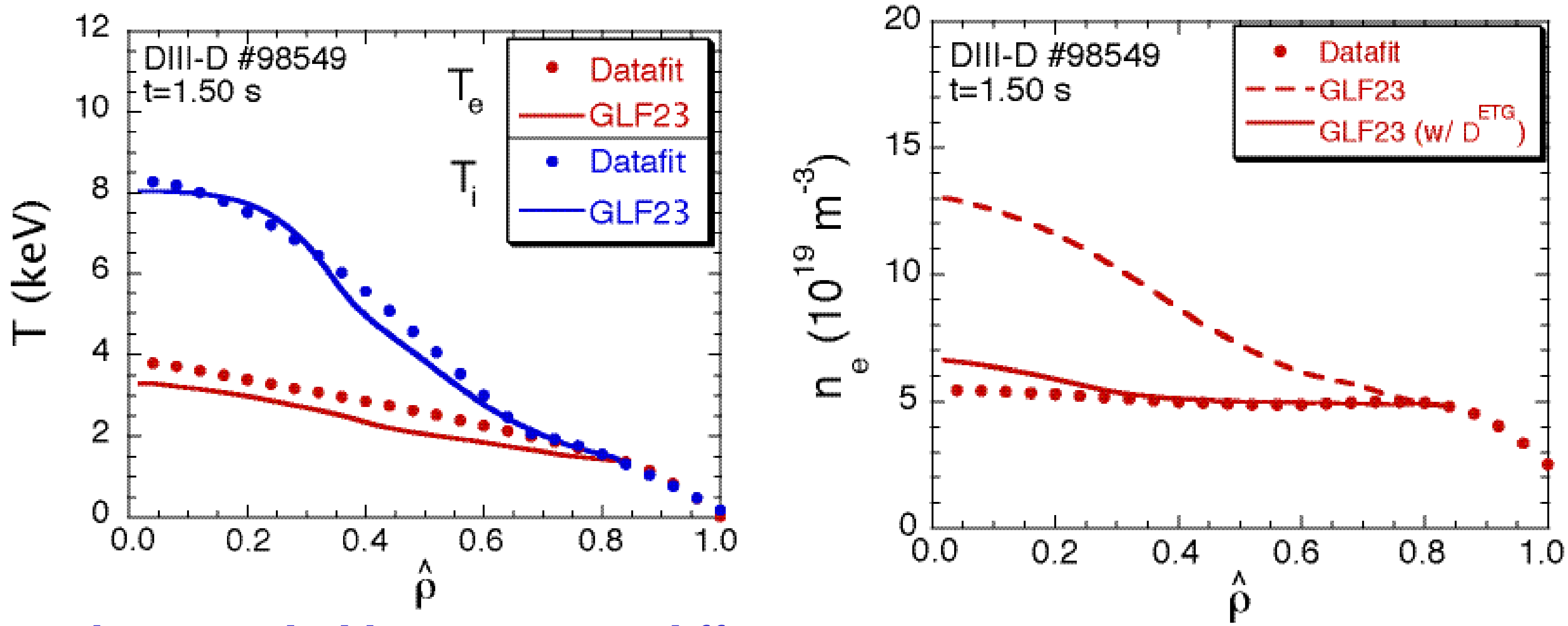
NON-LINEAR COUPLING FROM ETG TO ITG

- When there is no overlapping range of unstable wavenumber the ETG modes must couple non-linearly to the ions at low-k if they are to yield a non-adiabatic ion response.
- It is expected that ETG modes will have a non-linear cascade of energy from high to low wavenumber just as the ITG modes do.
- The ExB non- linearity produces a three wave coupling such that two ETG modes at short wavenumber which differ by a small wavenumber (vector) can transfer fluctuation energy to a short wavelength region.
- The strength of the three wave coupling will scale with the fluctuation amplitude of the ETG modes and hence any transport produced through this effect should be related to the level of electron thermal transport by ETG modes.
- The size of the non-linearly driven particle and ion momentum transport within a transport barrier is estimated by adding an ad-hoc transport coefficient proportional to the ETG driven electron thermal transport to GLF23.

GENERAL ATOMICS

REQUIRED ANOMALOUS PARTICLE TRANSPORT IS SMALLER THAN THE ETG ELECTRON THERMAL TRANSPORT

An ad-hoc particle diffusivity of 15% the ETG electron thermal diffusivity is found to give a density profile in agreement with experiment.

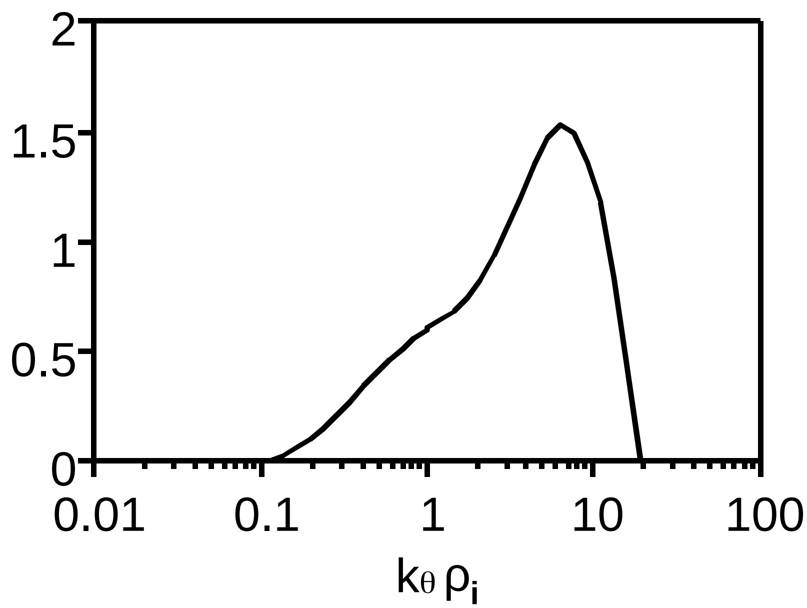


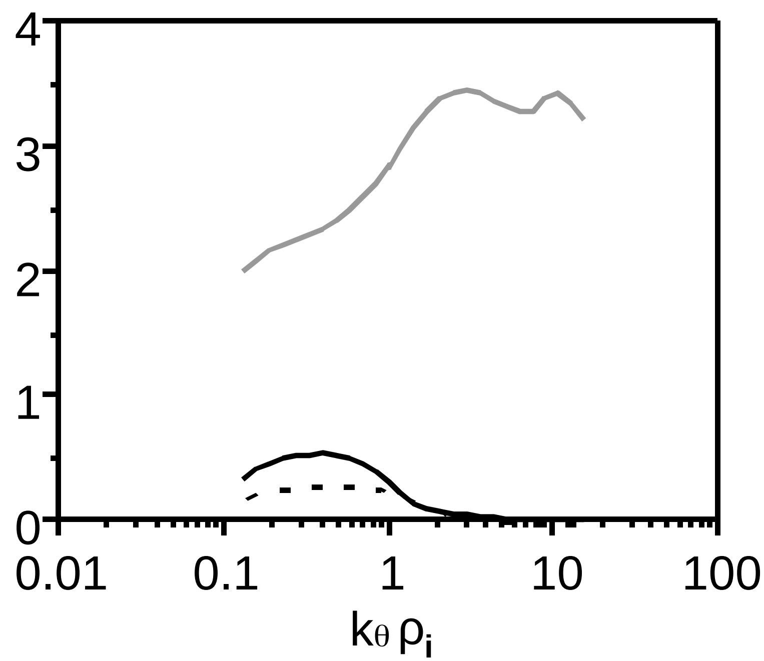
The required ad-hoc momentum diffusivity is 25%

IN THE OUTER REGION OF THE PLASMA THE ETG AND ITG MODES HAVE A STRONGLY OVERLAPPING INSTABILITY RANGE

Spectrum of driftwave growthrates normalized to Cs/a for DIII-D discharge 105663 at r/a=0.8

Quasilinear weights for:
Ion energy flux (black)
Electron energy flux (grey)
Particle flux (chain)





GENERAL ATOMICS

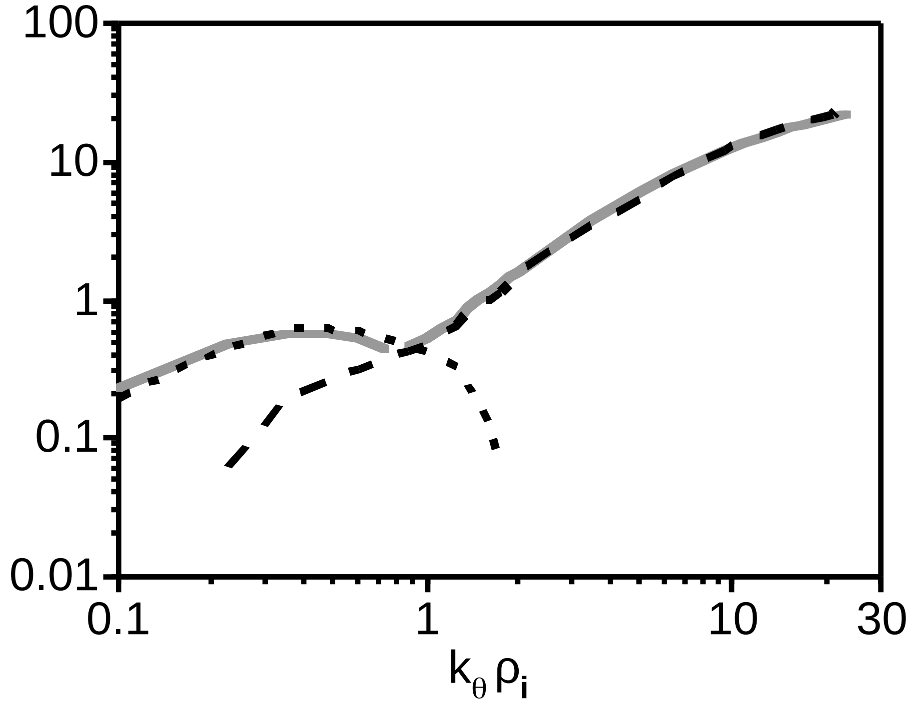
A NEW GYRO-LANDAU FLUID MODEL

- Gyro-Landau fluid (GLF) models give an accurate approximation to the kinetic linear growthrates of drift-ballooning modes in tokamaks.
- Even though the GLF model GLF23 has ETG modes they are assumed de-coupled from the ions (adiabatic ions).
- A new set of GLF equations is needed in order to treat the coupling between ETG modes and ions. The new model has three moments for trapped particles and twelve for passing particles of each species. The closure of the highest moments is done by fitting coefficients to minimize the error between the GLF and kinetic response functions. In the new model these closure coefficients become functions of the trapped fraction.
- A model for the loss of bounce averaging and the return of Landau damping for trapped particles has been developed. This enables the GLF model to seamlessly cover all wavenumber ranges from the lowest trapped ion modes to the highest ETG modes.
- A code to solve the new GLF model as an eigenvalue problem has been written so that sub-dominant modes can be found.

THE NEW GLF MODEL AGREES WELL WITH KINETIC LINEAR INSTABILITY CALCULATIONS

Growthrate spectrum (Cs/a units) for a/LT=6, a/Ln=1,s=1, alpha=0,Ti/Te=1,R/a=3,r/a=0.5 electrostatic. An initial value gyrokinetic calculation (grey) is compared with the new eigenvalue GLF code. The most unstable ion branch (chain) and electron branch (dashed) agree with the magnitude and crossover point of the kinetic code.

The region of overlapping ion and electron modes is revealed by an eigenmode calculation



GENERAL ATOMICS

CONCLUSIONS

- ETG modes are unstable deep into the ITG wavenumber range in the outer third of a tokamak plasma. This results in significant non-adiabatic ion response and ETG mode driven particle, ion thermal and ion momentum transport.
- In the middle zone of the tokamak ETG modes are not unstable for low wavenumber. There could still be a non-linear coupling between low and high wavenumber by which ETG modes produce transport at low wavenumber .
- In order to asses the magnitude of this non-linear transport ad-hoc particle and momentum diffusivities were added to GLF23. It was found that the ratio to the ETG electron thermal diffusivity required to match an experiment was 15% for particle and 25% for toroidal momentum transport. These are not small but are not so big as to rule out such a mechanism.
- A new gyro-Landau fluid model has been developed which can treat the coupling between ions and electrons over the full range of wavenumber. This model will have applications for growthrate analysis of data, as a non-linear simulation model for ETG-ITG coupling studies and as a fast eigenvalue solver in a transport model like GLF23.

GENERAL ATOMICS