Global Gyrokinetic Analysis of Turbulence and Transport Properties in NSTX Plasmas

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in collaboration with

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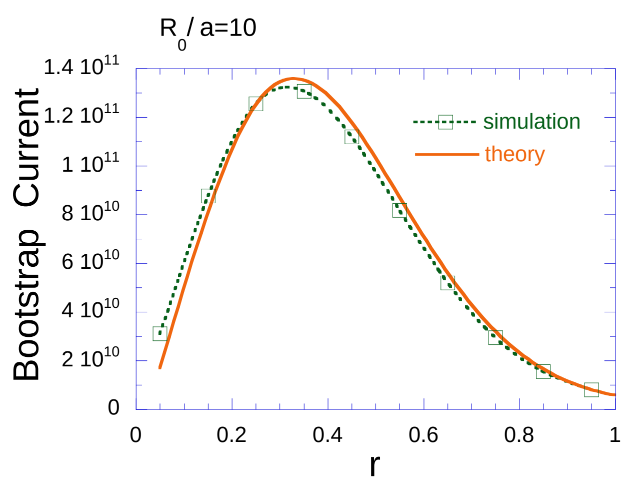
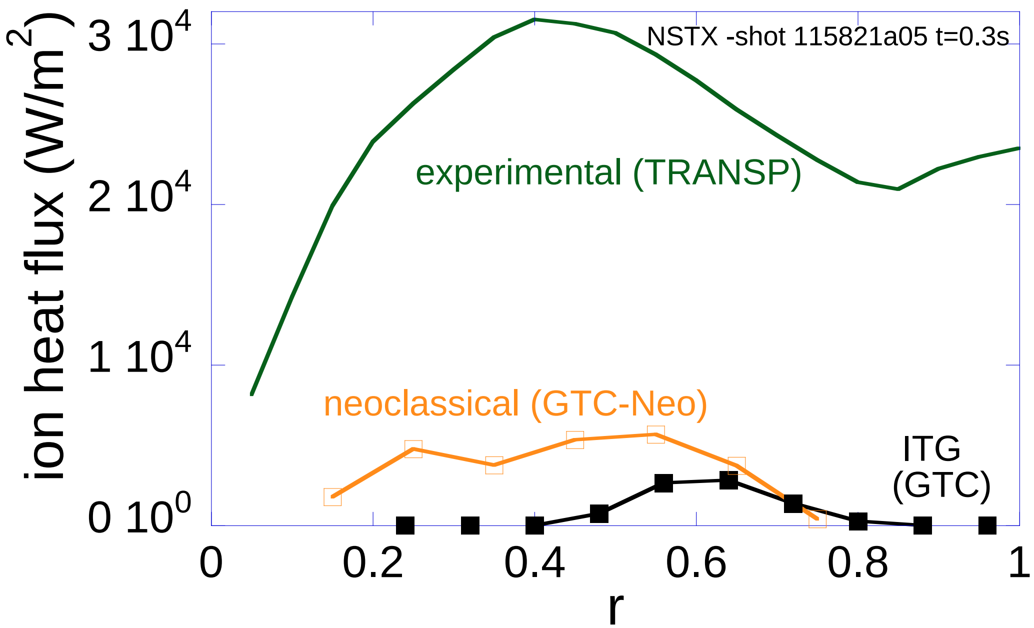
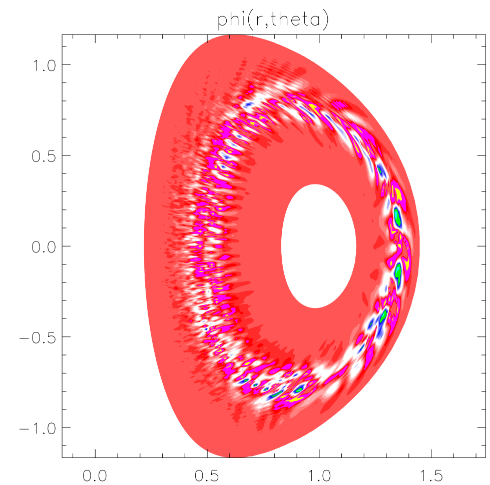
Gyrokinetic PIC Simulations of Neoclassical Transport

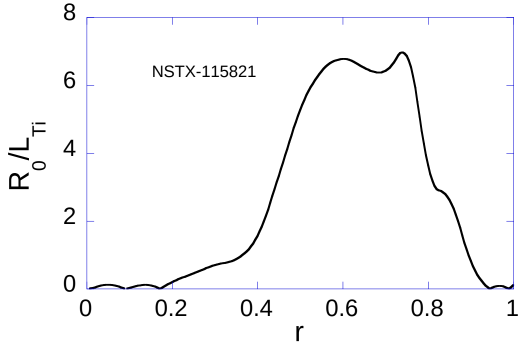
- GTC-Neo: δf global Gyrokinetic PIC Code
  [Wang et al., Comput. Phys. Commun. (2004); Phys. of Plasmas (2006)]
- Calculates neoclassical fluxes, E_r, j_b, etc
- Nonlocal physics due to large ion orbits
- Two species now: ions + electrons
- Momentum, energy and particle number conserving collisions
- Interfaced with MHD equilibrium codes and TRANSP data base
- Rigorously benchmarked against standard neoclassical theory



GTC Turbulence Simulations Show That ITG Modes Have Low Contribution to Energy Transport

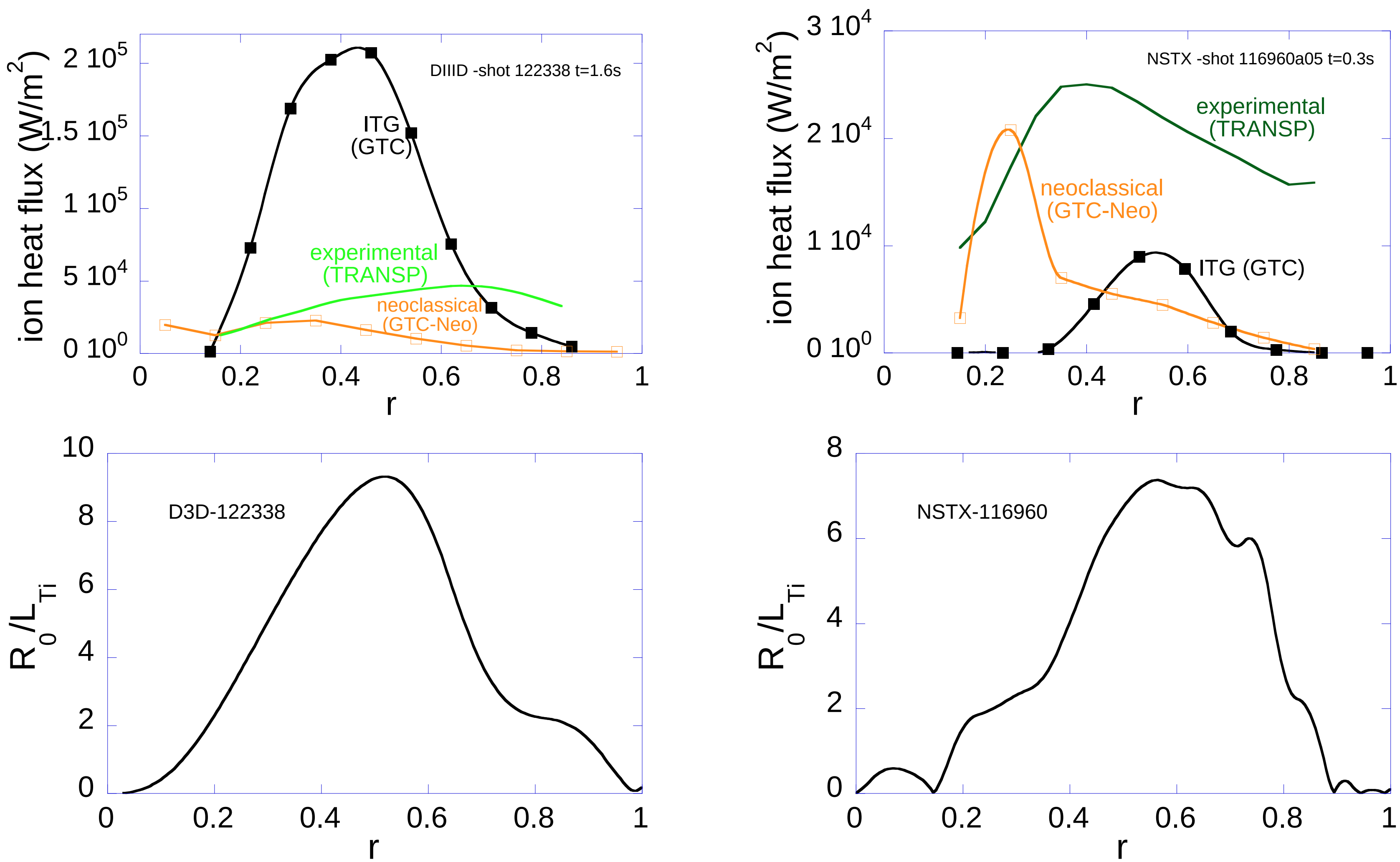






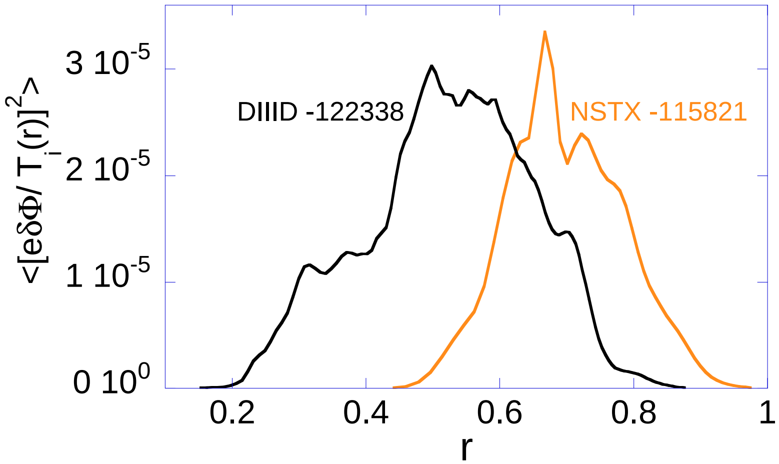
- – simulation radial domain: $0.2 \leq r \leq 1.0$; – adiabatic electrons; – equilibrium $\mathbf{E} \times \mathbf{B}$ shear flow not included; – ion-ion collisions included
- ITG turbulence has significant fluctuation amplitude, but drives small ion energy transport in NSTX plasma (sometimes below neoclassical level)!

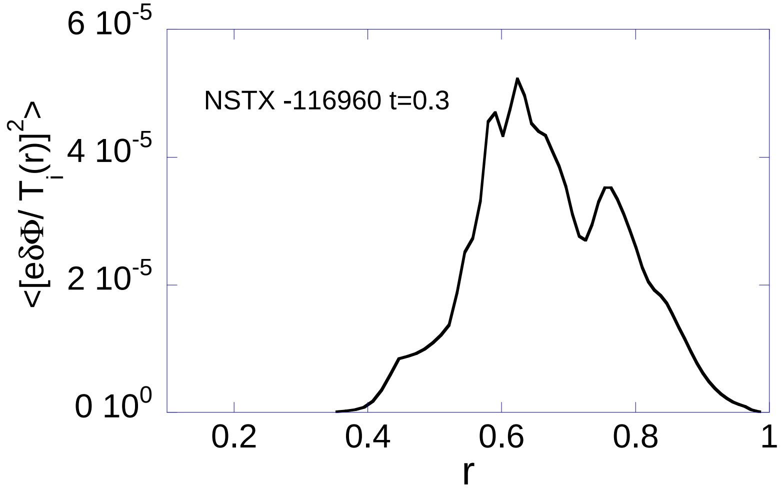
GTC Simulations Show that ITG Modes Are Relevant for DIIID, But Not for NSTX



- In contrast, in DIIID plasma, ITG turbulence can drive large transport ($\times 10$ neoclassical level)

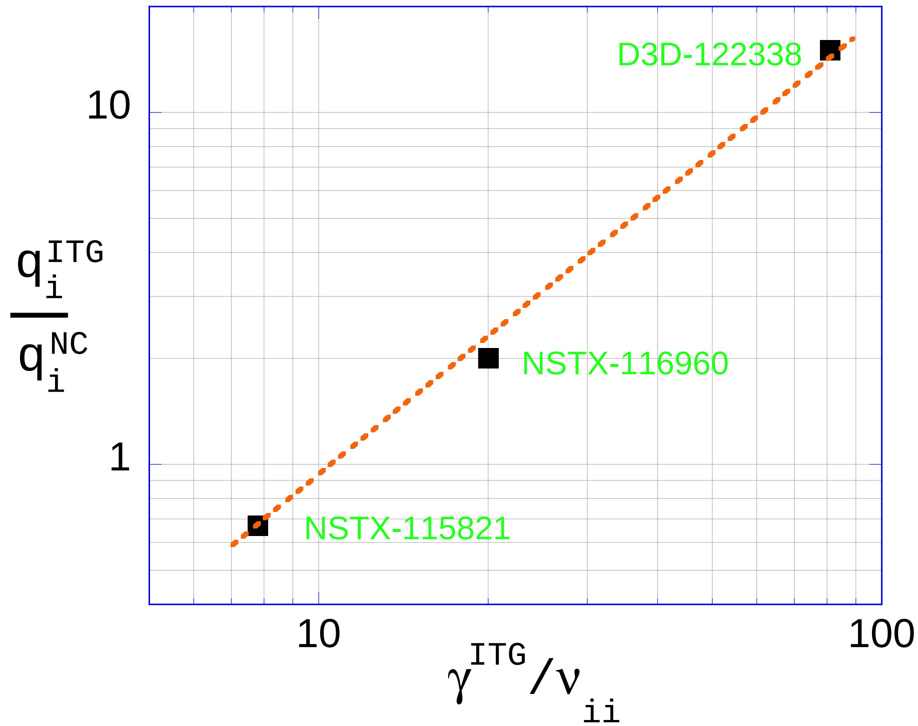
ITG Modes Drive Significant Potential Fluctuations





- Turbulence fluctuation levels for two machines are actually comparable $e\delta\phi/T_i < 1\%$

Mixed Scaling between ITG and Neoclassical Transport

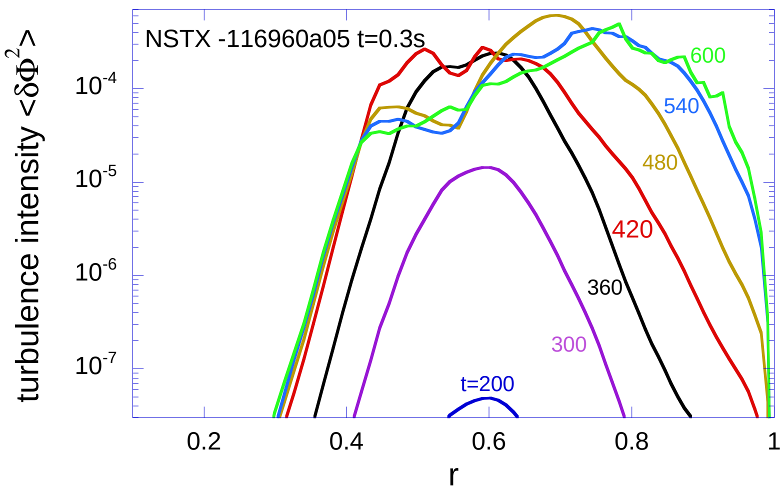


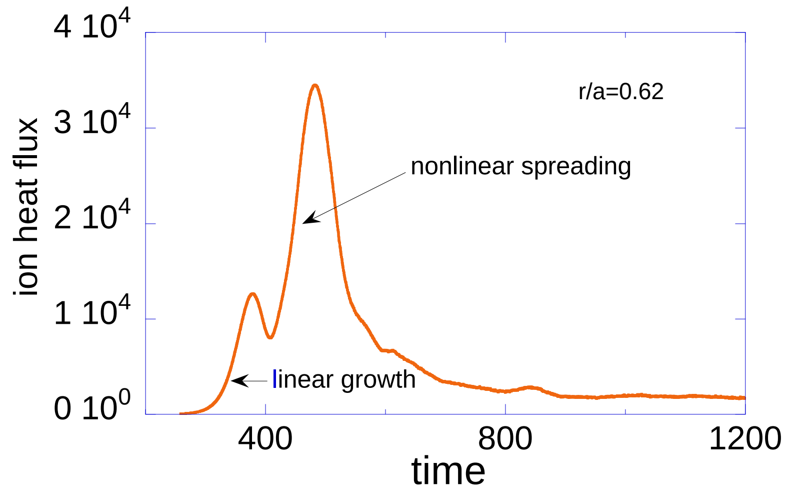
- Measured at locations around maximum R_0/L_{T_i}:

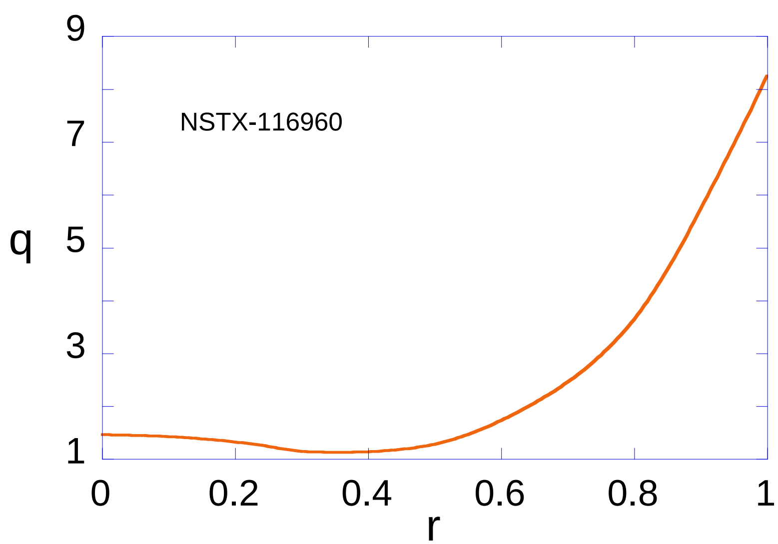
$$\frac{q_i^{\mathrm{ITG}}}{q_i^{\mathrm{NC}}} = \frac{\chi_i^{\mathrm{ITG}}}{\chi_i^{\mathrm{NC}}} \propto \frac{\gamma^{\mathrm{ITG}}}{\nu_{ii}} \qquad ?$$

- To compare neoclassical and turbulent transport, we may need to discuss them using a unified language

Transport Nonlocality due to Turbulence Spreading

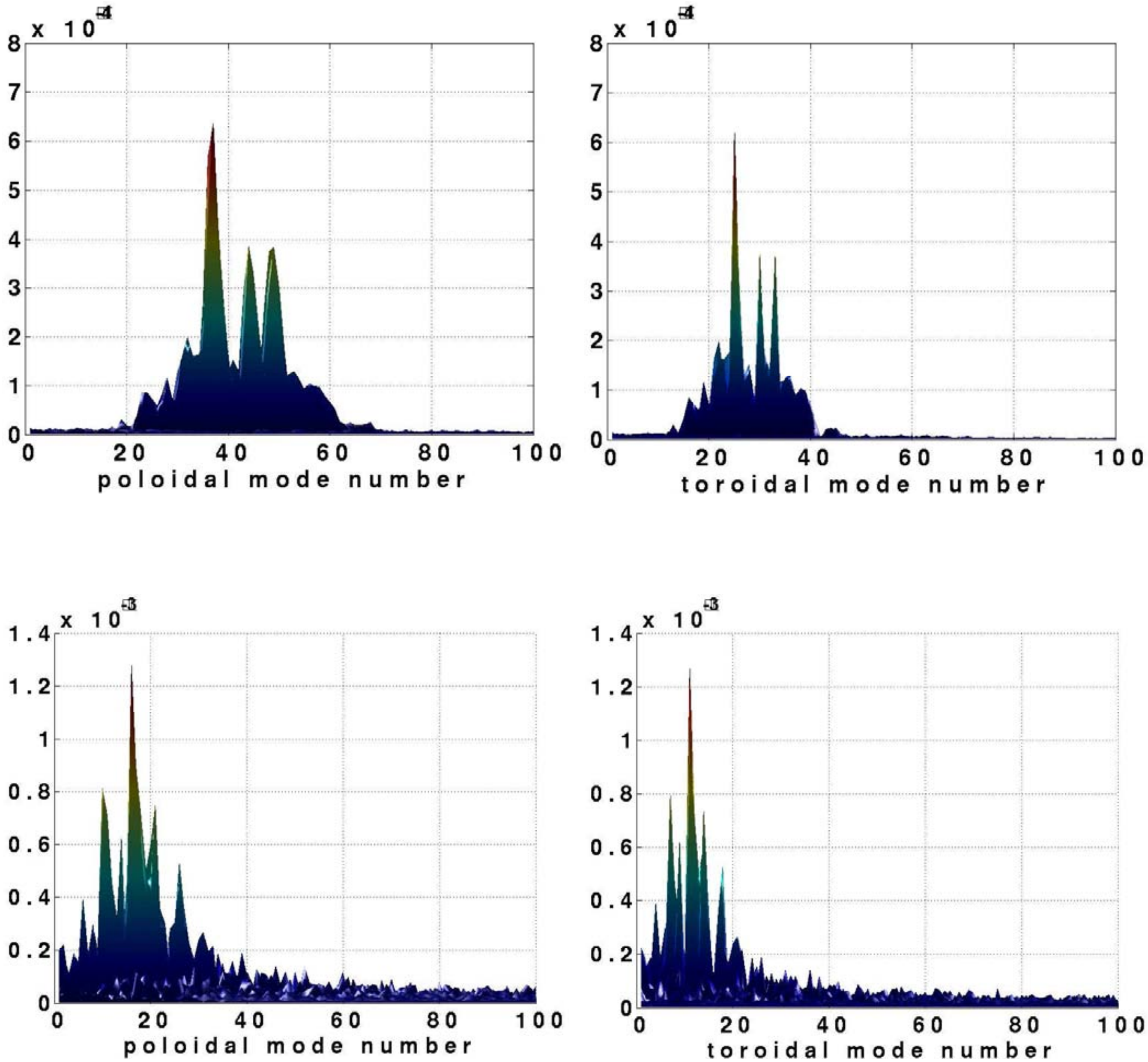






- Spreading in outward direction is more significant
- The reversed magnetic shear in the inner side may provide a stronger damping

ITG Turbulence Spectral in NSTX Plasma



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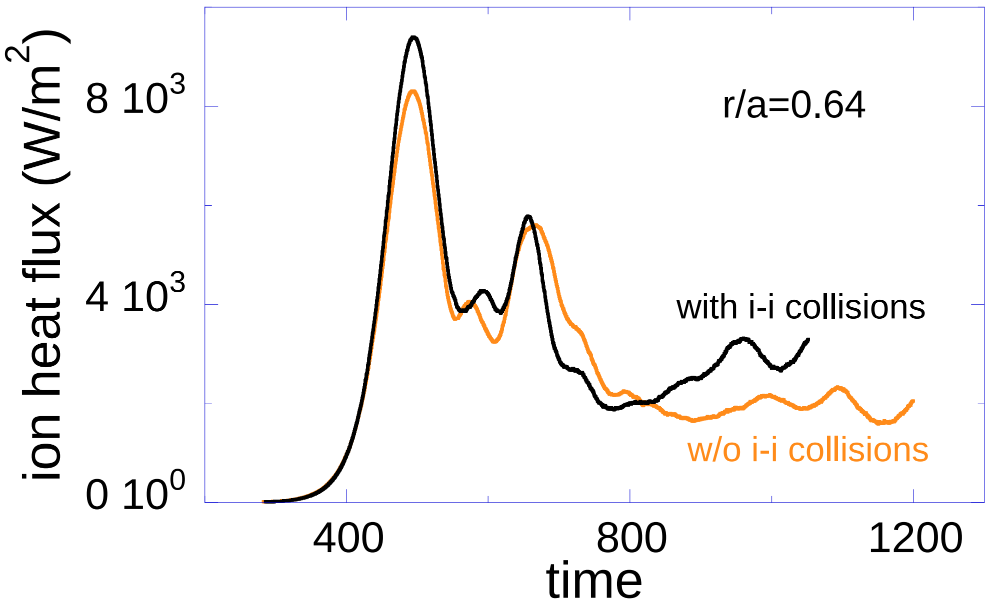
Effect of Coulomb Collisions



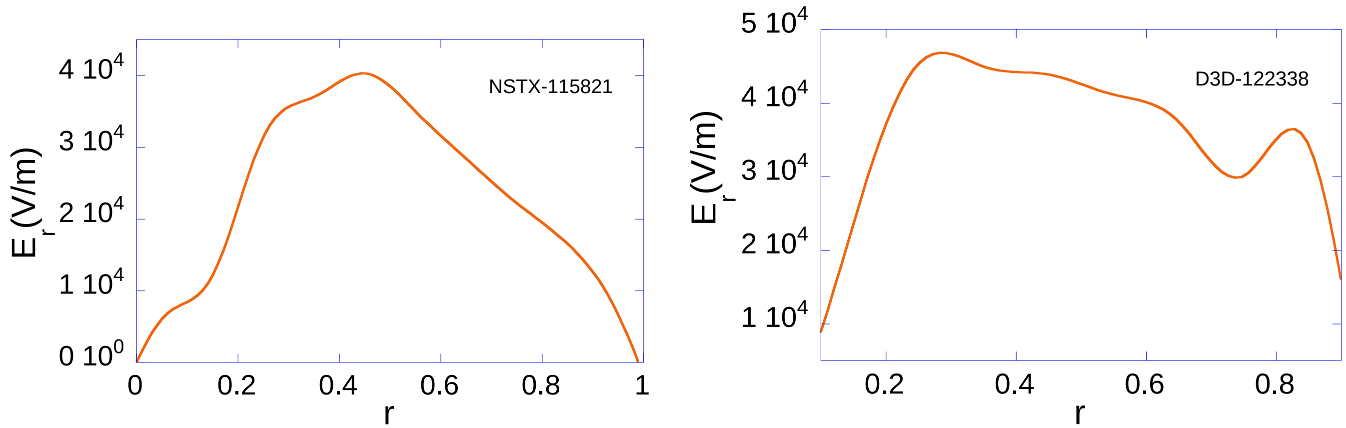
- Linear ion-ion collisions:

$$C^l_{ii}(\delta f) = \underbrace{C(\delta f, f_0)}_{\text{(drag \& diffusion)}} + \underbrace{C(f_0, \delta f)}_{\text{(effect of perturbed field particles, neglected)}}$$

- Collisions enhance ITG driven ion heat flux, but not significantly

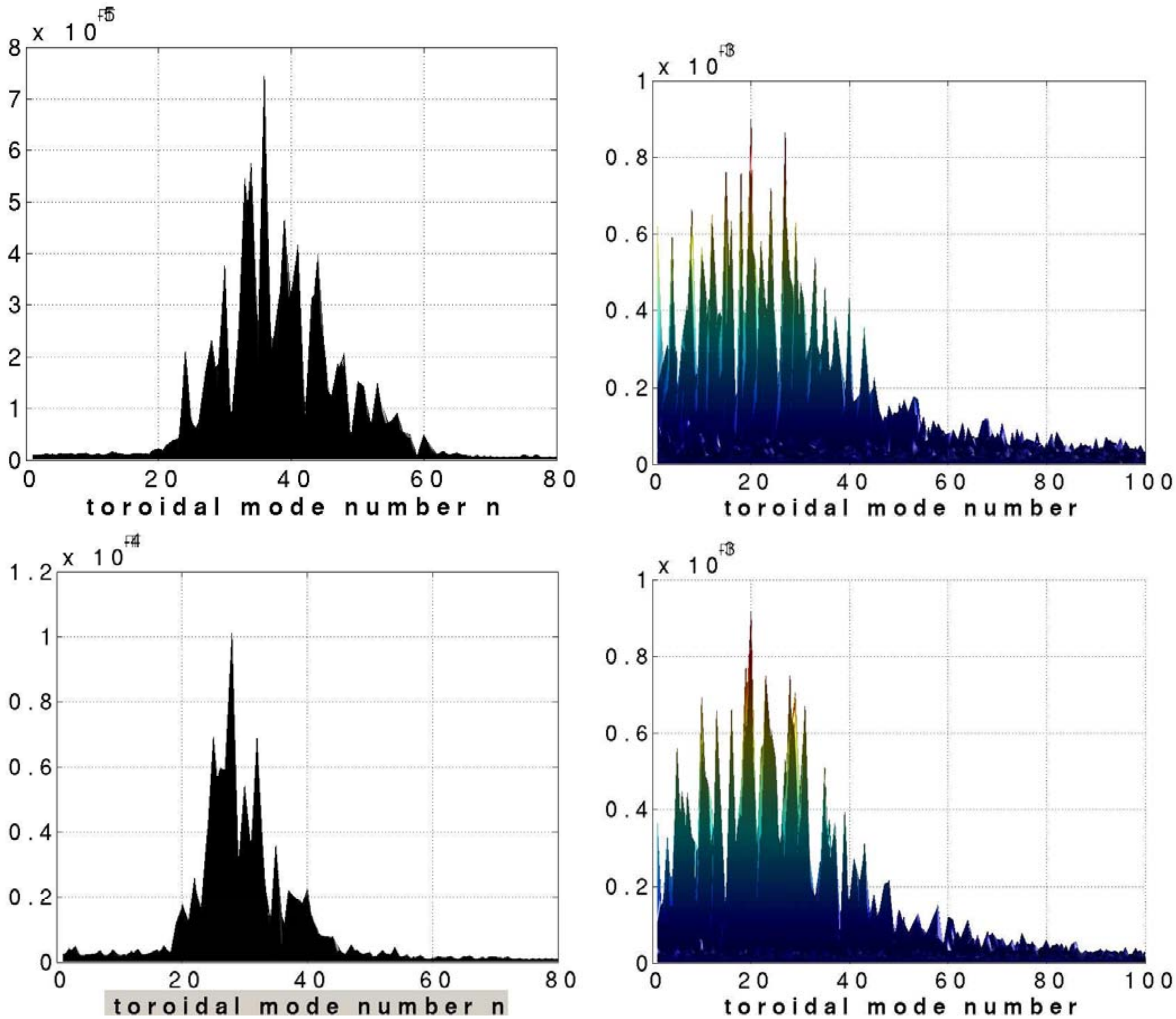
- It may expect more sensitive dependence on collisions in marginal instability regime

Effect of Equilibrium $\mathbf{E} \times \mathbf{B}$ Shear Flows



- Equilibrium radial electric field is determined by neoclassical dynamics and calculated by GTC-Neo consistently
- ITG is stabilized when equilibrium $\mathbf{E} \times \mathbf{B}$ shear flow is included

Fluctuation Spectrum Shift due to Applied Equilibrium $E \times B$ Flow



Global ETG Simulation for NSTX Discharge Is a Huge Computational Challenge

- Motivated by recent results of high-k measurements in NSTX experiments
- Huge number of grid point needed in poloidal direction due to strongly nonuniform geometry
- Number of grid point: 1000(radial) $\times$ 100000(poloidal)
  (compared to typical flux-tube simulation: 256×256)
- Size of ETG simulation of NSTX experiment is $2 \sim 3$ order of magnitude larger than that of ITG (computationally impractical!)

Ongoing Investigations

- Effects of trapped electrons on NSTX turbulence transport
  - trapped electron enhancement of ITG driven ion energy transport
  - TEM turbulence driven transport

Summary

Global gyrokinetic PIC simulations have been applied to analysis both turbulent and neoclassical transport properties for NSTX experiments

- In NSTX plasmas, ITG driven ion energy transport is of neoclassical level.
- In contrast, for DIIID discharges, ITG turbulence is shown to drive large transport ($\times 10$ neoclassical level).
- Turbulence fluctuation levels for two machines are actually comparable ($\sim e\delta\Phi/T_i < 1\%$).
- A mixed transport scaling (?)

$$\frac{q_i^{\rm ITG}}{q_i^{\rm NC}} = \frac{\chi_i^{\rm ITG}}{\chi_i^{\rm NC}} \propto \frac{\gamma^{\rm ITG}}{\nu_{ii}}$$

- Self-consistent equilibrium $\mathbf{E} \times \mathbf{B}$ flows can strongly stabilize ITG.
- Effect of collisions is weak.

Gyrokinetic PIC Simulations of Turbulent Transport

- General Geometry GTC: generalized gyrokinetic simulation model implemented based on GTC [Lin et al, Science (1998)] architecture [Wang et al., Phys. of Plasmas (2006)]

- Shaped cross-section; experimental profiles; consistent rotation and equilibrium $\mathbf{E} \times \mathbf{B}$ flow; linear Coulomb collisions; $\cdots$

- Interfaced with MHD equilibrium codes and TRANSP data base

- Carefully benchmarked in simple geometry limit