Momentum and Heat Transport in Electron Turbulence Regimes

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PPPL

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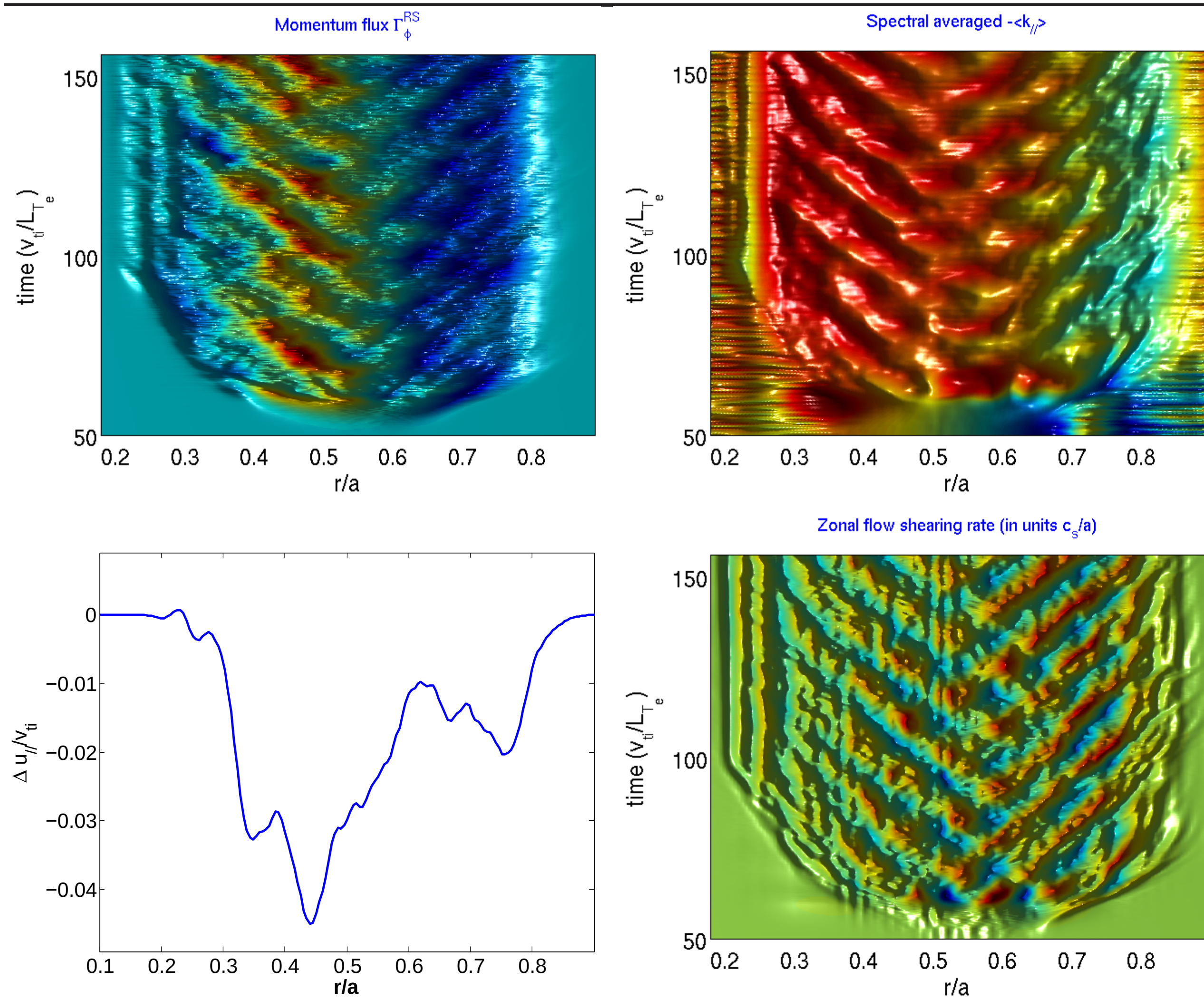
Global gyrokinetic GTS simulations of:

– **CTEM turbulence driven intrinsic rotation**

– **ETG turbulence driven electron heat transport in NSTX**

2010 NSTX Results and Theory Review
Nov. 30 – Dec. 2 2010

Nonlinear flow generation due to turbulent residual stress offers a universal mechanism to drive intrinsic rotation



$$\Gamma_\phi \propto -\chi_\phi \frac{\partial U_\phi}{\partial r} + V_p U_\phi + \Pi^{rs}_{r,\phi}$$

- CTEM turbulence
- initially rotation free
- momentum-source-free
- mean $\mathbf{E} \times \mathbf{B}$ included
- from GTS simulation

(Wang et al., PRL'09; PoP'10)

- Residual stress driven by both fluctuation intensity and intensity gradient
- Universal mechanism to break $k_{||}$ symmetry: self-generated low-ω ZF shear
- Rotation produced in co-current direction, consistent with expt. trend

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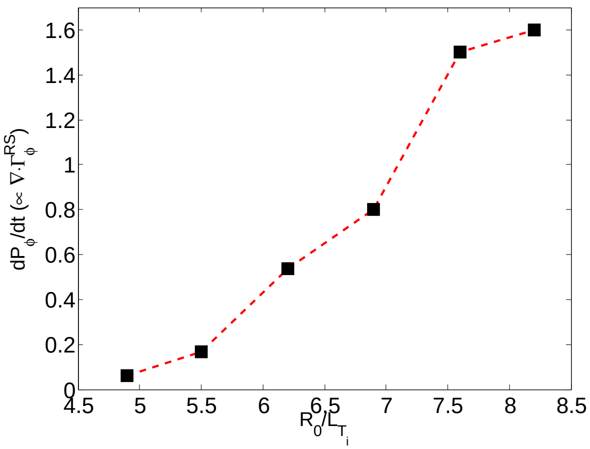
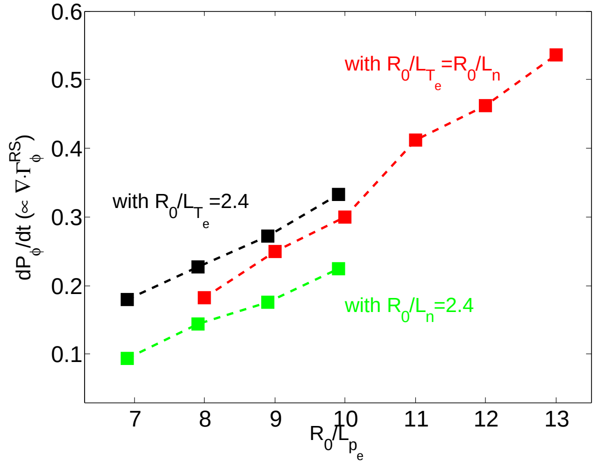
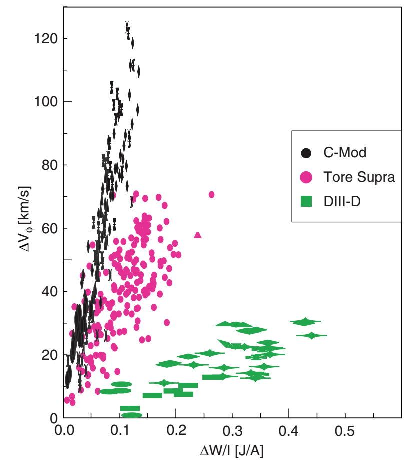
Turbulent residual stress induced intrinsic torque scales linearly with plasma gradients



ITG case



CTEM case



Rice scaling

- CTEM-driven intrinsic torque $\sim \nabla P_e$ – highly interesting to test in NSTX
- Physics origin is from dependence of fluctuation intensity and zonal flow shear on turbulence drive
- Consistent with experimental observations
  - $\Delta V_\phi \sim \Delta W_p / I_p$ in H-mode plasmas of multiple devices (Rice et al. '07)
  - $V_{\phi,\mathrm{central}} \sim \nabla T_{\mathrm{i,edge}}$ in C-MOD I-mode plasmas (Rice, IAEA FEC'10)
  - intrinsic rotation increases with pressure gradient

    in JT-60U (Yoshida et al. '08); in LHD (Ida et al. '10); $\cdots$

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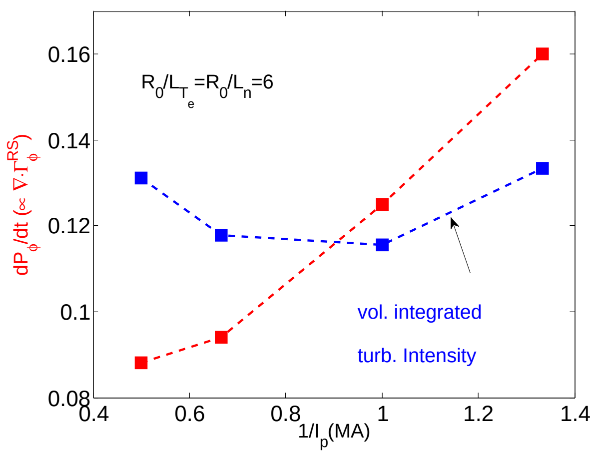
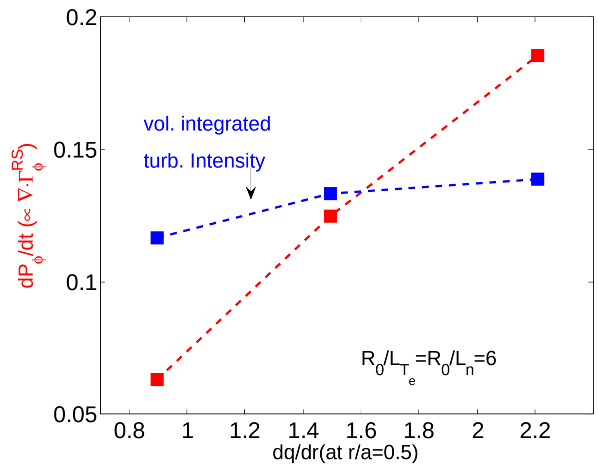
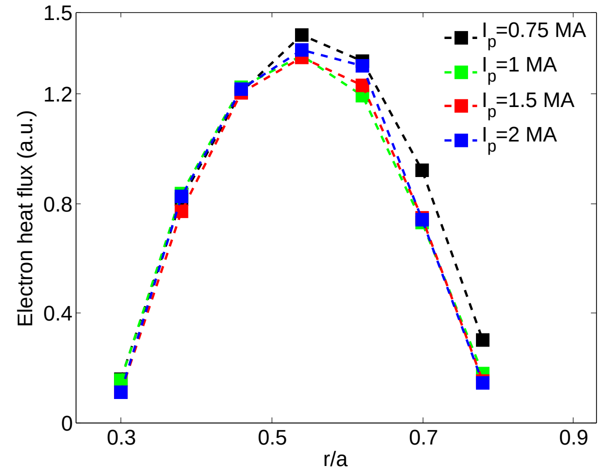
Turbulence nonlinearly driven intrinsic rotation inversely scales with plasma current, reproducing empirical scaling







(Wang et al., submitted PRL)

- I_p scan performed with CTEM turbulence
- Hold $B_{\rm ext}$ & P fixed, varying I_p (as expt. do)
- Origin of current scaling is found to be due to enhanced $k_{||}$ symmetry breaking induced by increased magnetic shear as current decreases
- Prediction can be tested by NSTX (or by revisiting existing data base)
- Qualitatively distinct I_p-dependence between different transport channels

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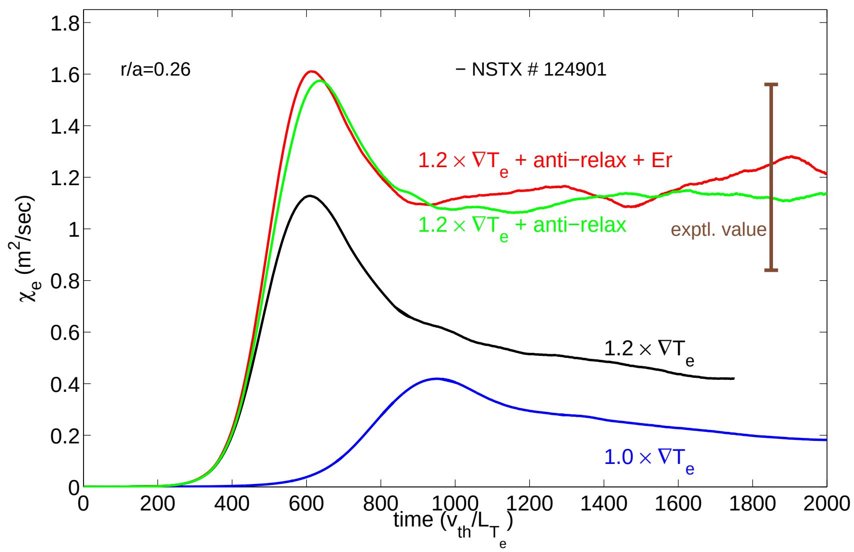
Nonlinear global GTS simulations of ETG turbulence and transport in NSTX



- Higher level, stationary saturated flux obtained
- Eliminating influence of profile relaxation is essential (particularly in marginal ETG regime)
- $\chi_e \sim 1.2\ \mathrm{m}^2/\mathrm{sec}$ – within certain uncertainty in plasma local profiles, ETG may drive significant electron heat transport in NSTX
- Equilibrium $\mathbf{E} \times \mathbf{B}$ shear (calculated from GTC-NEO) has little impact on simulated electron heat flux

Ethier et al., IAEA FEC 2010

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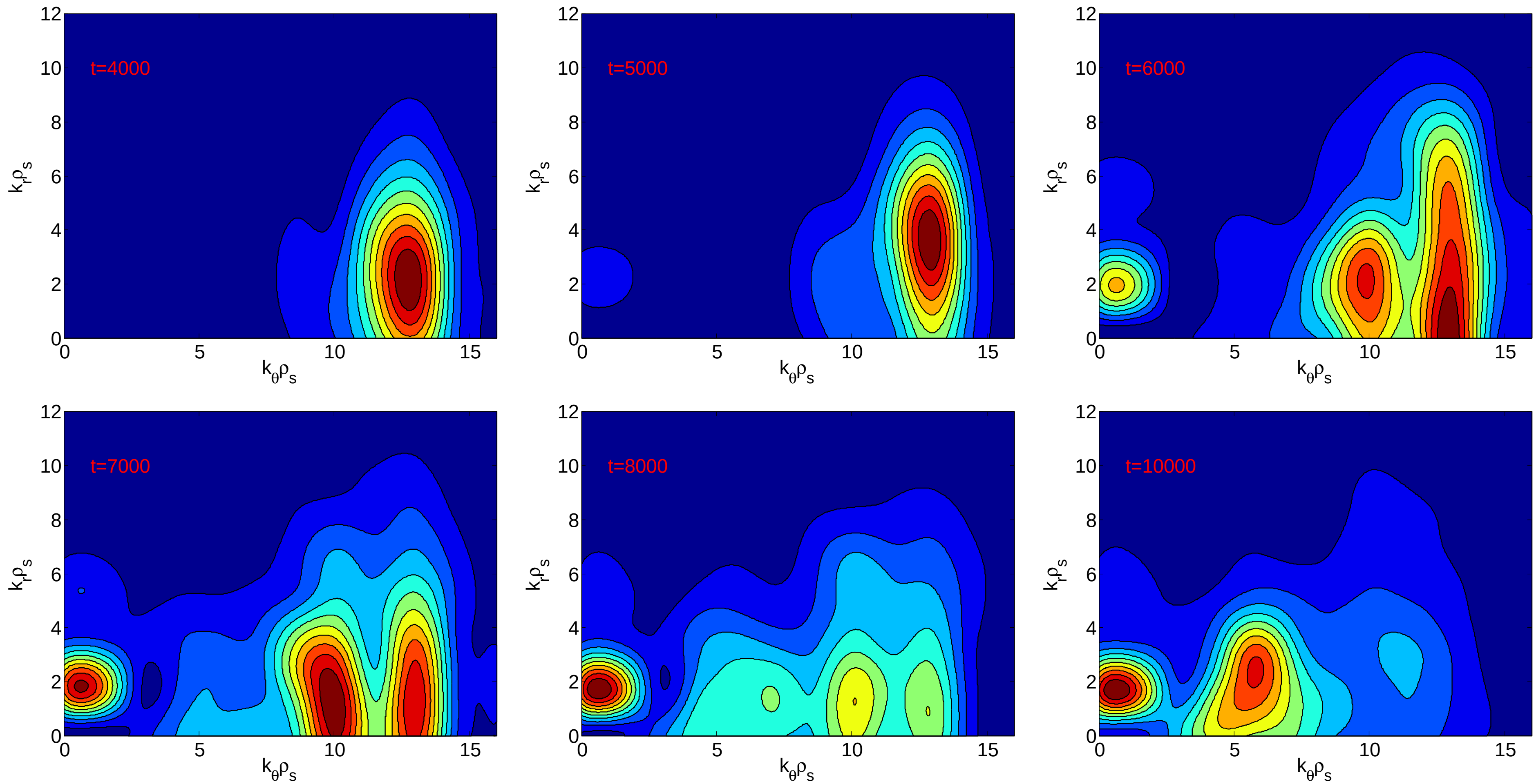
Nonlinear ETG saturation via strong direct energy coupling to e-GAM/zonal-flows



- Strong spectrum anisotropy: $k_\theta \gg k_r$
- Zonal flows continuously grow
- Strong energy coupling to e-GAM
- e-GAM & ZF damping important

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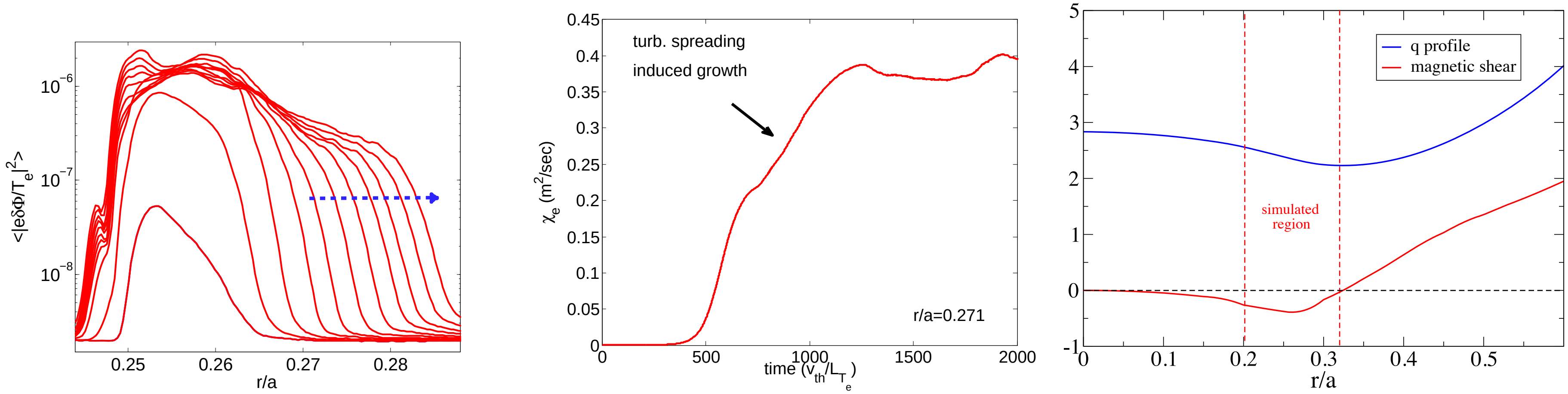
ETG turbulence spreading and effect are identified



- Ballistic outward spreading (to positive magnetic shear region)
- How fast: $\sim (1-2) \times 10^{-3} c_s$; how far: $\sim$ a few tens of ρ_e
- Little inward spreading due to reversed magnetic shear

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