Transport of Toroidal Angular Momentum in CTEM Turbulence

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Outline

- Motivation and general approach
- Formulation
- Simulation results
  - Intrinsic rotation and residual momentum flux
  - Rigid rotation. Momentum convection
  - Sheared rotation. Momentum diffusivity
- Summary

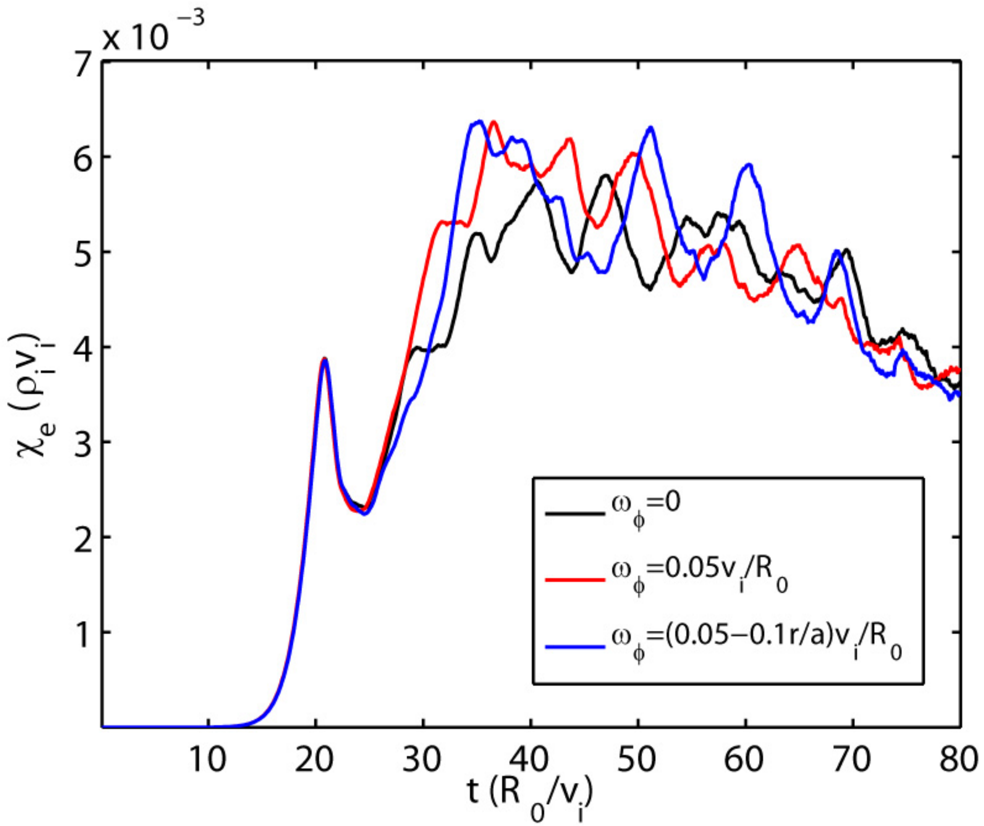
Motivation and general approach

- Rotation plays important role in turbulence stabilization
- Intrinsic rotation and momentum pinch are important when external torque is insufficient
- Understanding of momentum transport in electron-driven turbulence is important for ITER
- Toroidal angular momentum flux is generically decomposed into diffusive, convective, and residual flux
- Simulations with no background rotation, with rigid rotation, and with sheared rotation allow to address each component of momentum flux separately

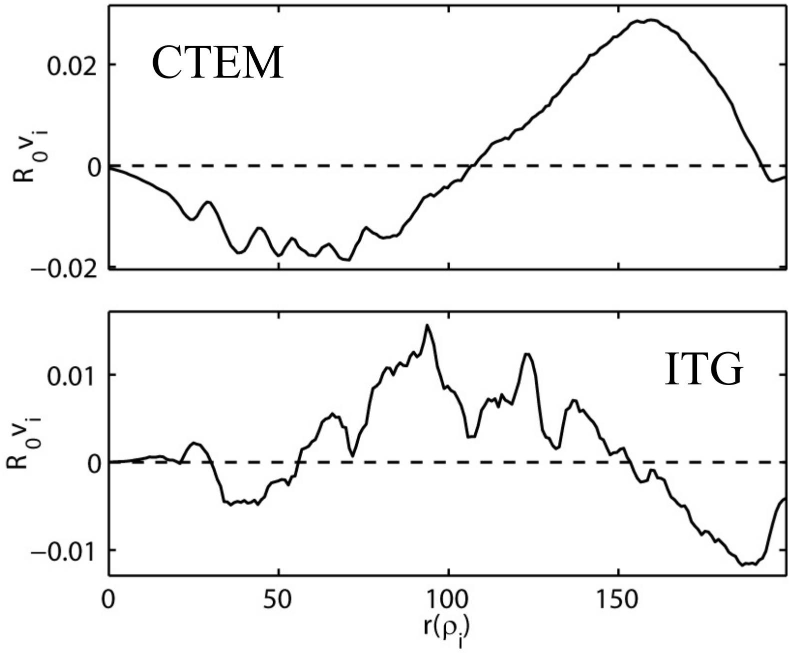
- ► Global electrostatic nonlinear PIC simulation of core plasma region
- ► Gyrokinetic δf treatment for ions
- ► Fluid-kinetic hybrid electron model based on expansion of electron response:
    - ► In the lowest order electrons are adiabatic
    - ► In higher order electron dynamics described by drift kinetic equation
- ► Fluctuations are set to be zero at the boundaries – no momentum source or sink through the boundaries

Small rotation velocity and velocity shear to prevent turbulence modification

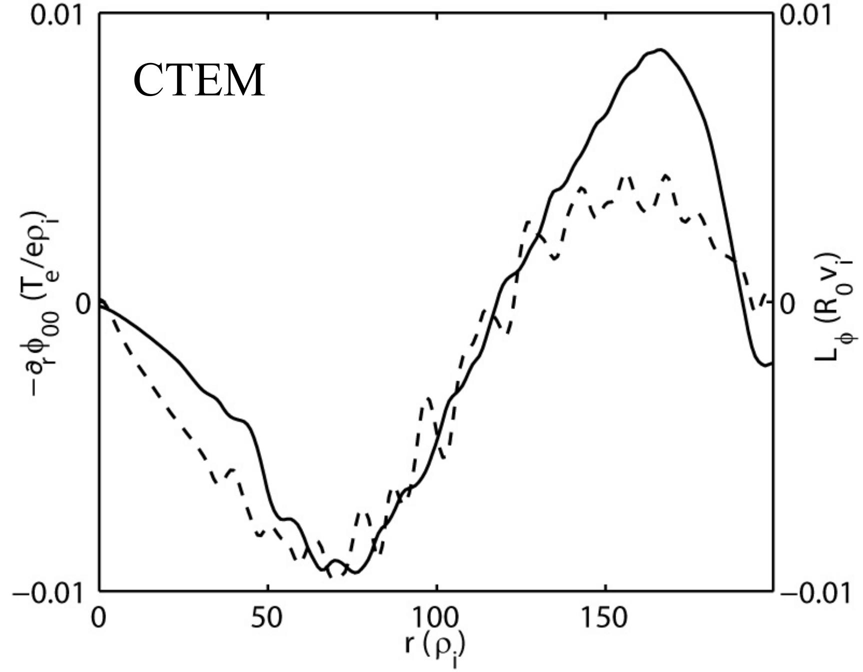
- Typical rotation velocity $v_\phi \sim 0.1 v_i$
- Typical shearing rate $\gamma_\phi \sim 0.3 v_i/R_0$ compared to the turbulence linear growth rate $\gamma_{CTEM} \sim 0.6 v_i/R_0$



- Simulations with *no background rotation*



Initial (dashed line) and final (solid line) radial profiles of toroidal angular momentum



Perturbed angular momentum profile (solid line) and zonal flow profile (dashed line)

- Rotation is in the opposite direction for ITG and CTEM turbulence

- Intrinsic rotation profiles correlates with self-generated radial electric field profile

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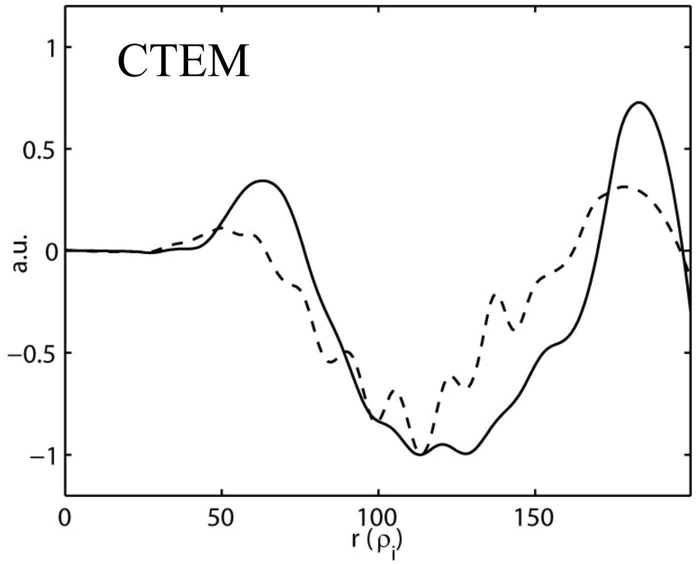
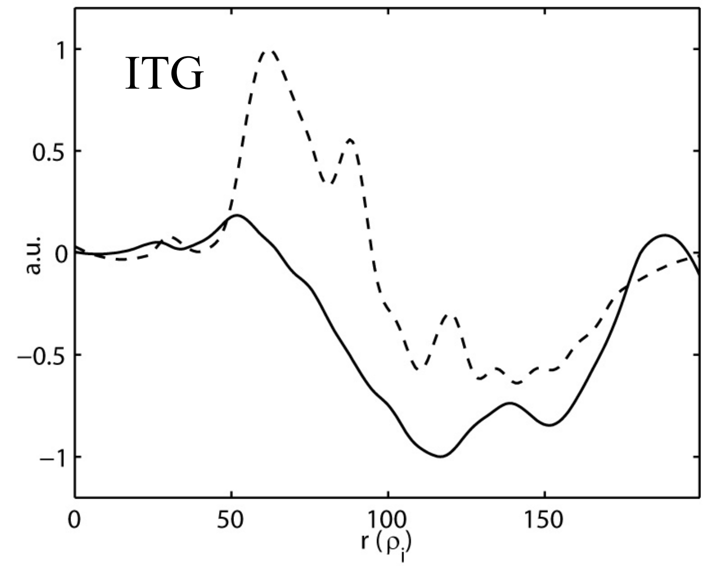
Residual stress and symmetry breaking



Time-averaged normalized radial profiles of toroidal angular momentum flux (solid line) and self generated radial electric field shear (dashed line). CTEM case with R_0/L_{Ti}=2.2, R_0/L_{Te}=6.9, R_0/L_n=2.2.



Time-averaged normalized radial profiles of toroidal angular momentum flux (solid line) and self generated *negative* radial electric field shear (dashed line). CTEM case with R_0/L_{Ti}=6.9, R_0/L_{Te}=2.2, R_0/L_n=2.2

- Momentum flux correlates with radial electric field shear which likely provides parallel symmetry breaking mechanism
- Sign in correlation is opposite for CTEM and ITG

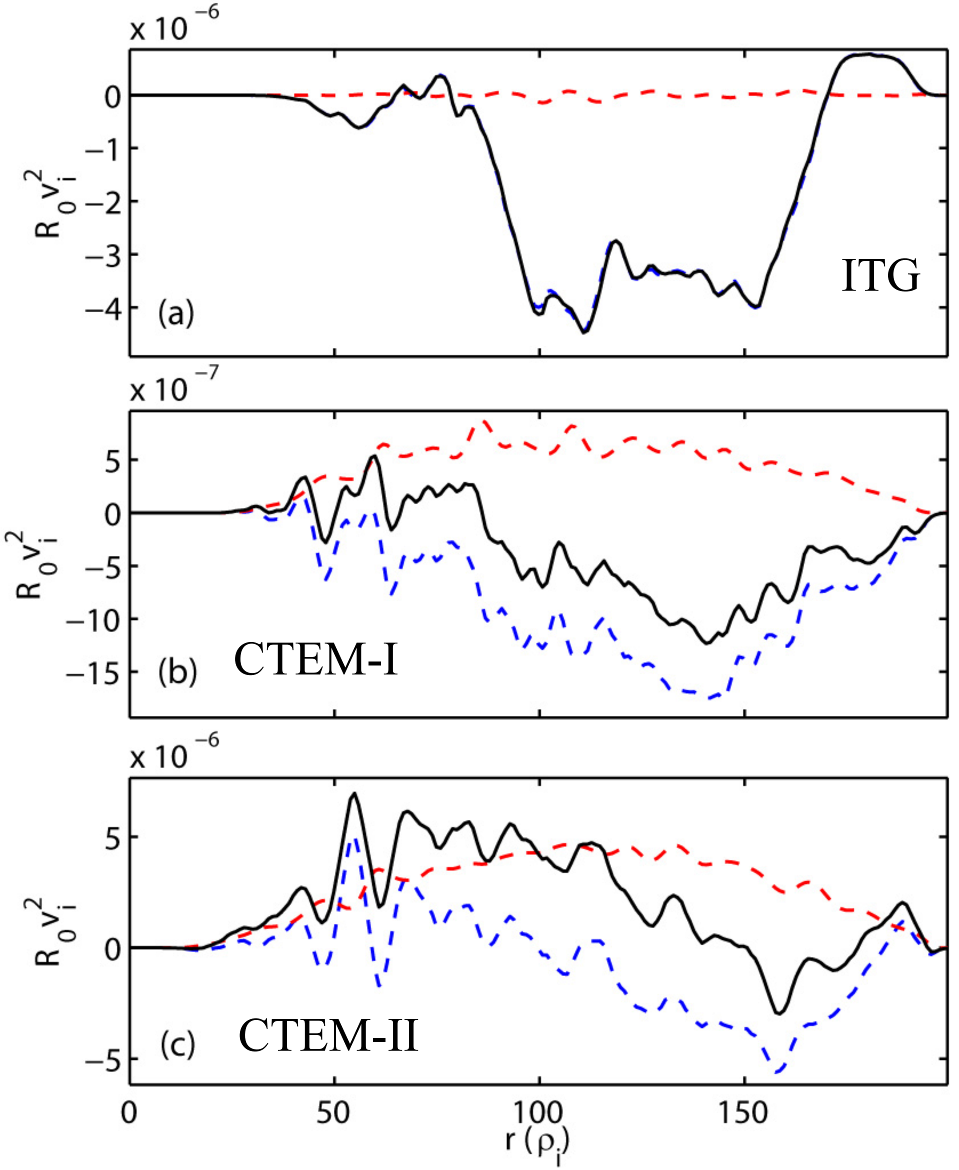
- Simulations of plasma with *rigid rotation*
- Convective flux of toroidal angular momentum consists of (outward) particle convective flux (red) and inward TEP-like pinch (blue)

$$\Gamma_{conv} = \frac{1}{n}\Gamma_n L_\phi + V_\phi L_\phi$$

ITG: R_0/L_{Ti}=4.5, R_0/L_{Te}=0, R_0/L_n=1

CTEM-I: R_0/L_{Ti}=0, R_0/L_{Te}=4.5, R_0/L_n=1

CTEM-II: R_0/L_{Ti}=0, R_0/L_{Te}=4.5, R_0/L_n=4.5



Parameter studies of convective momentum flux

R_0/L_{Ti}	R_0/L_{Te}	R_0/L_n	V_ϕ/I	Γ_n/nI
4.5	0	1	-23.4	0
4.5	0	2.2	-17.7	0.1
4.5	0	4.5	-4.3	4.8
9.0	0	1	-20.9	0
9.0	0	2.2	-17.7	0.1
0	4.5	1	-6.2	3.3
0	4.5	2.2	-5.0	4.1
0	4.5	4.5	-1.5	6.8
0	9.0	1	-6.3	3.2
0	9.0	2.2	-5.5	4.2

- No explicit temperature gradient dependence of momentum pinch observed for a given turbulence regime

- Density steepening reduces momentum pinch velocity

Structure of toroidal momentum flux

- Simulations of plasma with *sheared rotation*

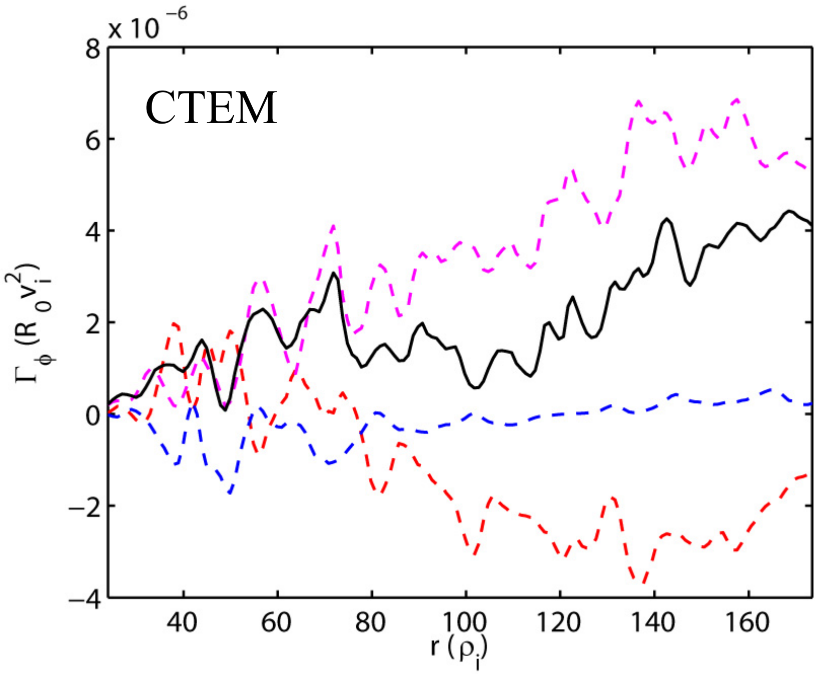
$$\omega_\phi = (0.05 - 0.1 r/a) v_i / R_0$$

- Residual (red), convective (blue) and diffusive (green) fluxes are separated

- Volume averaged diffusive flux is dominant but off-diagonal components are important

- Intrinsic Prandtl number:

$$\mathrm{Pr} = \chi_\phi / \chi_i$$



$$\mathrm{Pr}_{\mathrm{ITG}} \approx 0.7$$

R_0/L_{Ti}=6.9, R_0/L_{Te}=2.2, R_0/L_n=2.2

$$\mathrm{Pr}_{\mathrm{CTEM}} \approx 1.0$$

R_0/L_{Ti}=2.2, R_0/L_{Te}=6.9, R_0/L_n=2.2

Summary

- Intrinsic rotation is observed with opposite direction in CTEM and ITG turbulence
- Perturbed momentum profile follows the profile of self-generated radial electric field (ZF)
- Particle flux plays important role in momentum convection, leading to possible reversal of the momentum convective flux
- Momentum pinch flux shows no explicit dependency on background temperature gradient, but strongly depends on the density gradient
- Intrinsic Prandtl number is found to be slightly larger in the CTEM turbulence compared to the ITG turbulence