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Large-scale structures in gyrofluid ETG/ITG turbulence and ion/electron transport

TH/8-5Ra: **Dynamics of large-scale structure and electron transport in tokamak microturbulence simulations**

J. Q. Li[1,2] , Y. Kishimoto[3,2] , N. Miyato[2] , T. Matsumoto[2] , J. Q. Dong [1]

TH/8-5Rb: **Study of drift wave-zonal mode system based on global Landau-fluid ITG simulation in toroidal plasmas**

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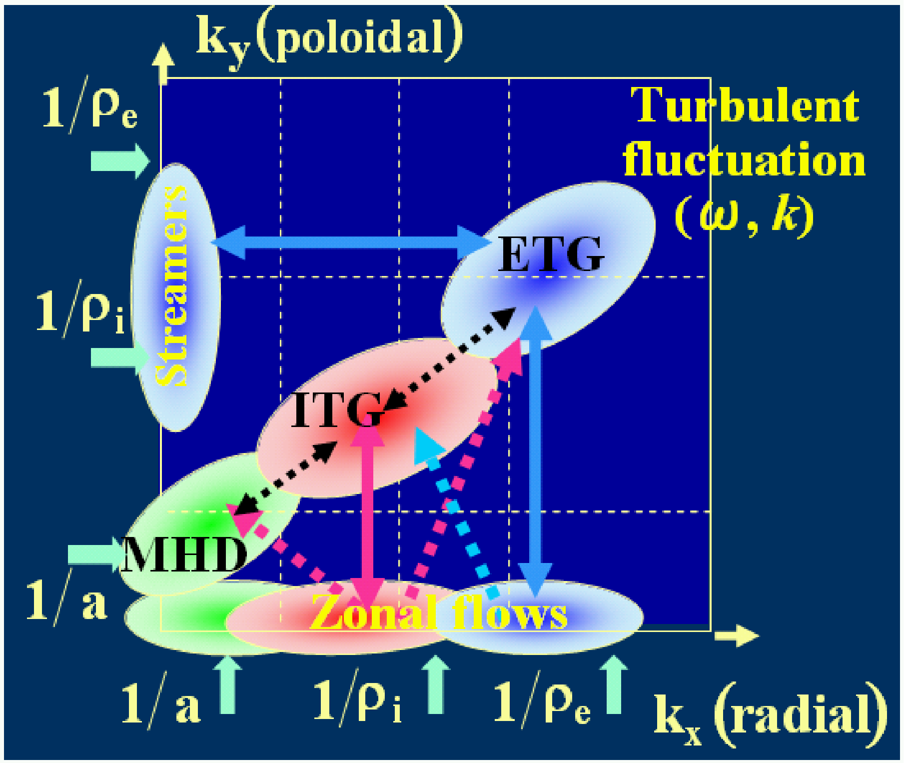
Backgroud and motivation

Large-scale structures can be nonlinearly generated in plasma turbulence: zonal flows or streamers

Different large-scale structure dynamics → fluctuation (transport) suppression/enhancement



Zonal flows and streamers are linked to low-frequency long wavelength generalized Kelvin-Helmholtz (GKH) mode

Kim & Diamond

- Turbulence interaction and anomalous transport is complex
- Structure formation in experiments is interesting and useful: transport barriers

Our point is to:

- Study how to form different large-scale structures in plasma turbulence and their local/global characteristics
- Look for some key parameters to explore the way how we can control turbulence/transport

Purpose and main points

To approach the goal, two gyrofluid codes developed

Local toroidal/slab EM ETG

For electron transport, may ETG, TEM or MHD activities be candidates?

- ► **Basic physics of structure formation**
- ► **Key parameters to control turbulence/transport**

Jenko/Dorland ; Li/Kishimoto; Idomura; Lin; Labit/Ottaviani;…..

Global toroidal EM ITG/MHD

ITG modeling seems to be successful for ion transport!

- ► **Global properties in tokamak turbulence**
- ► **Transport controlling**

Lin et al, GTC code; Waltz, et al, GYRO code; Dorland, et al. GS2 code; Idomura et al. GT3D code; Thyagaraja, et al. CUTIE code; ……

Outline in this talk

- ► **Pattern selection in ETG turbulence: zonal flows or streamers; Streamer formation and electron transport in toroidal EM ETG** ***(TH/8-5Ra)***
- ► **Global characteristics of zonal flows in toroidal ITG turbulence and transport controlling** ***(TH/8-5Rb)***

Large-scale structures in ETG turbulence and electron transport

Structure formation via modulation in ETG

Gyrofluid ETG modeling → 2D CHM turbulence:

$$(1-\nabla_\perp^2)\partial_t\tilde{\phi} = \partial_y\tilde{\phi} + [\tilde{\phi},\nabla_\perp^2\tilde{\phi}]$$

Pump wave:

$$\tilde{\phi}_p = \phi_0 e^{i\vec{k}\cdot\vec{x}-i\omega_0 t} + c.c. \qquad \omega_0 = \frac{-k_y}{1+k_0^2}$$

Sidebands:

$$\tilde{\phi}_\pm = \phi_\pm e^{i\vec{k}_\pm\cdot\vec{x}-i\omega_\pm t} + c.c. \qquad \vec{k}_\pm = \vec{k}_0 \pm \vec{k}_q$$

$$\omega_\pm = \omega_0 \pm \omega_q$$

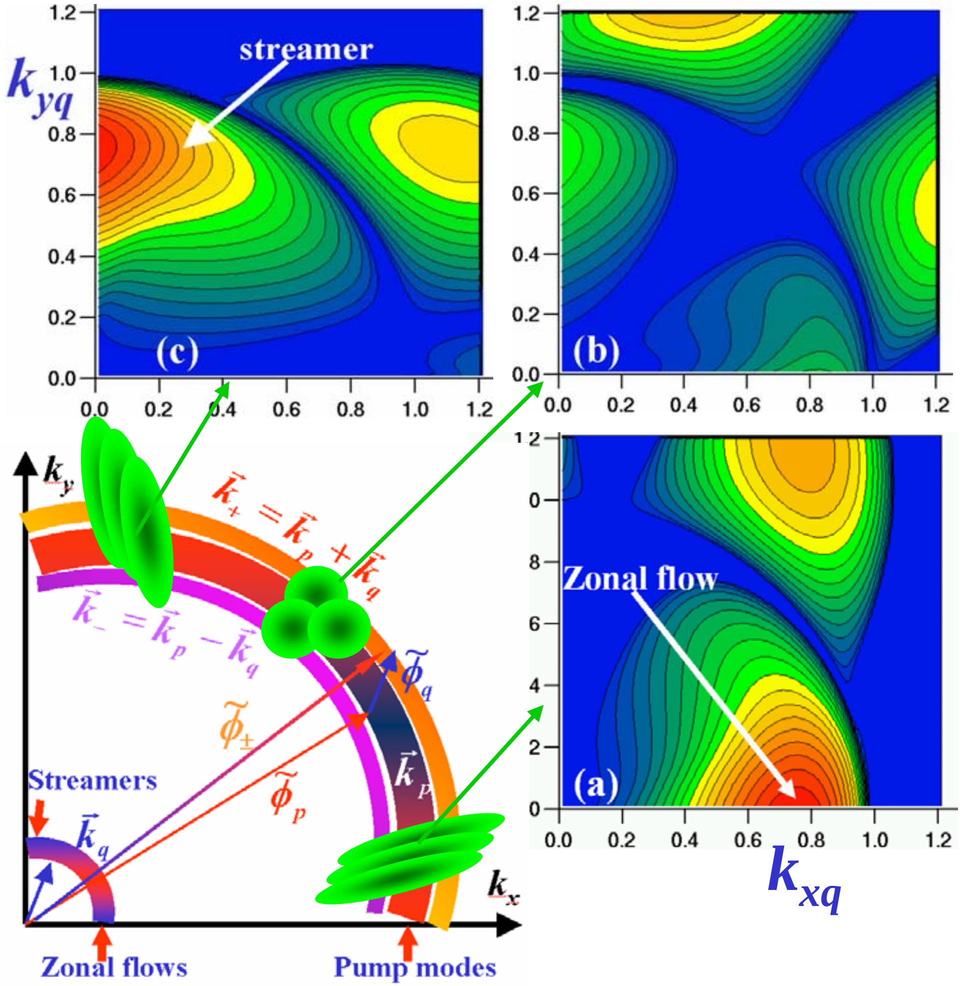
Secondary mode:

$$\tilde{\phi}_q = \phi_q e^{i\vec{q}\cdot\vec{x}-i\omega_q t} + c.c. \qquad \omega_q \ ???$$

Dispersion relation for GKH

$$F(\omega_q, k_q, \omega_0, k_0, \phi_0^2) = 0$$

Growth rates show global spectral structure of secondary GKH



Generation of zonal flow/streamer depends on turbulence anisotropy

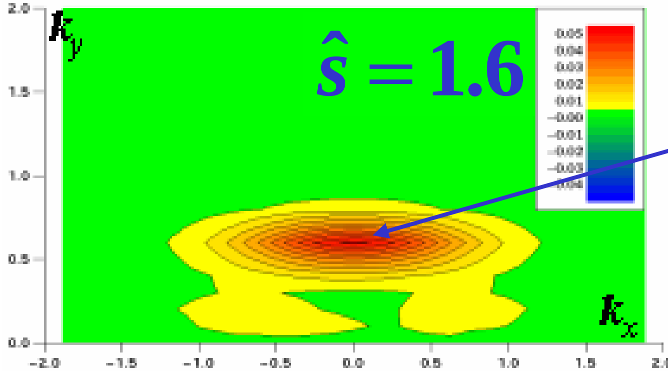
Pattern selection in 3D slab ETG turbulence

Drift wave theory: mode width depends on magnetic shear, etc.

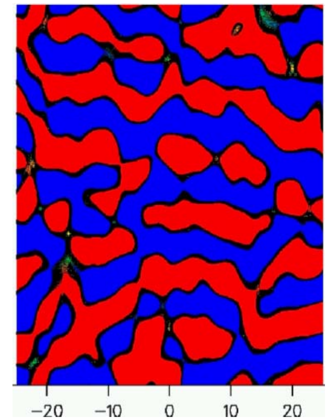
Weak turbulence: eigenmode superpositioned

↔ Magnetic shear may govern turbulence anisotropy

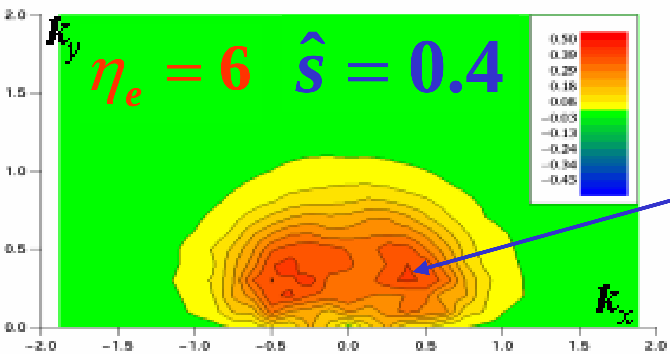
→ **Pattern selection**



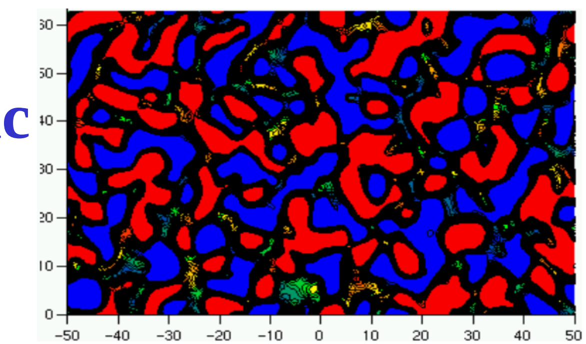
Streamers dominated



$\hat{s}$ ↑



Almost isotropic ETG spectrum



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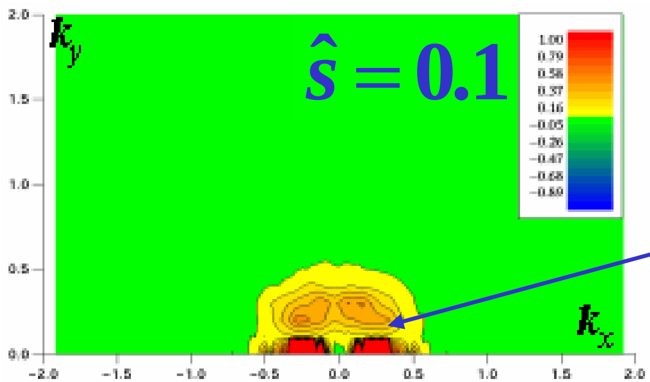
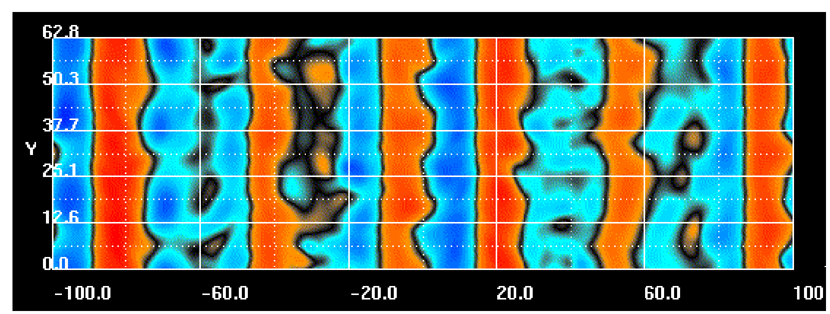


Zonal flows dominated



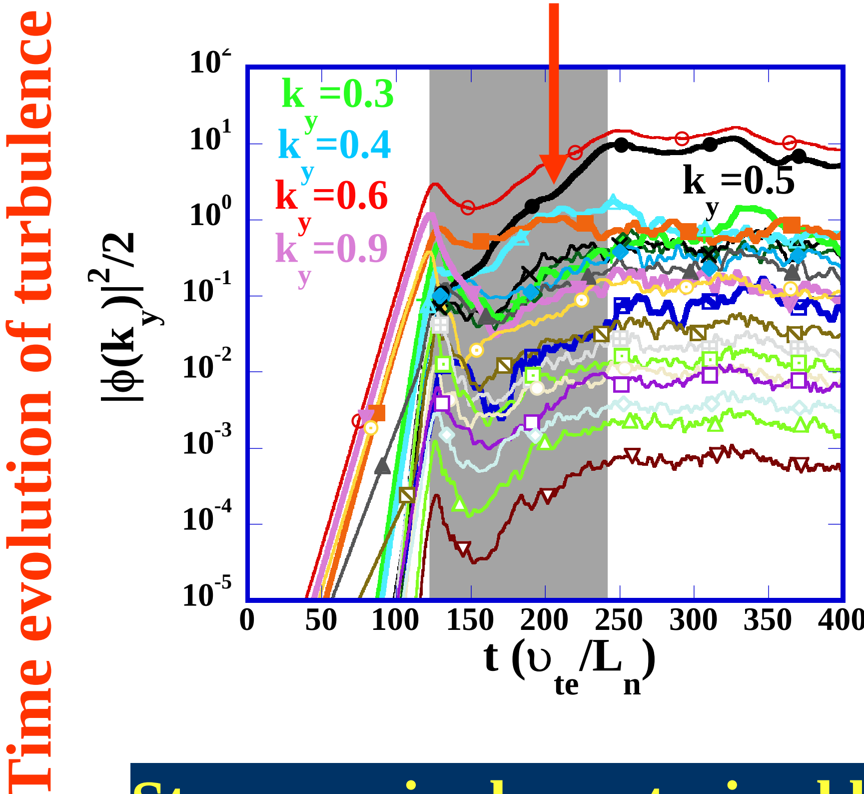
Streamers in toroidal EM ETG turbulence

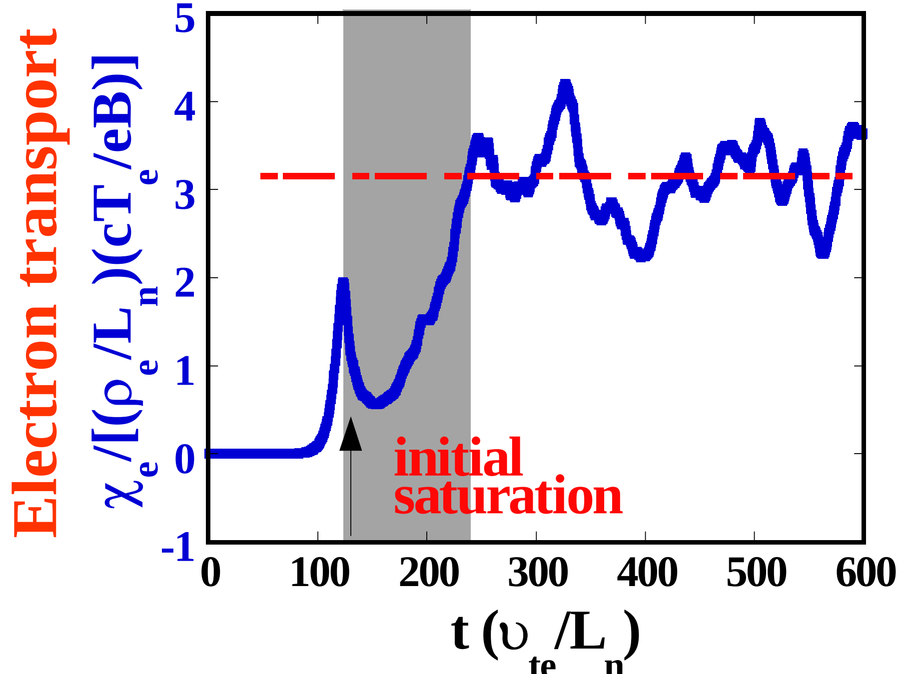
- **3D gyrofluid Toroidal EM ETG simulations**

  $\hat{s} = 0.6, \eta_e = 3.2, \varepsilon_n = L_n / R = 0.45$

Streamer is nonlinearly excited through modulation instability

Electron transport is around Gyro-Bohn level

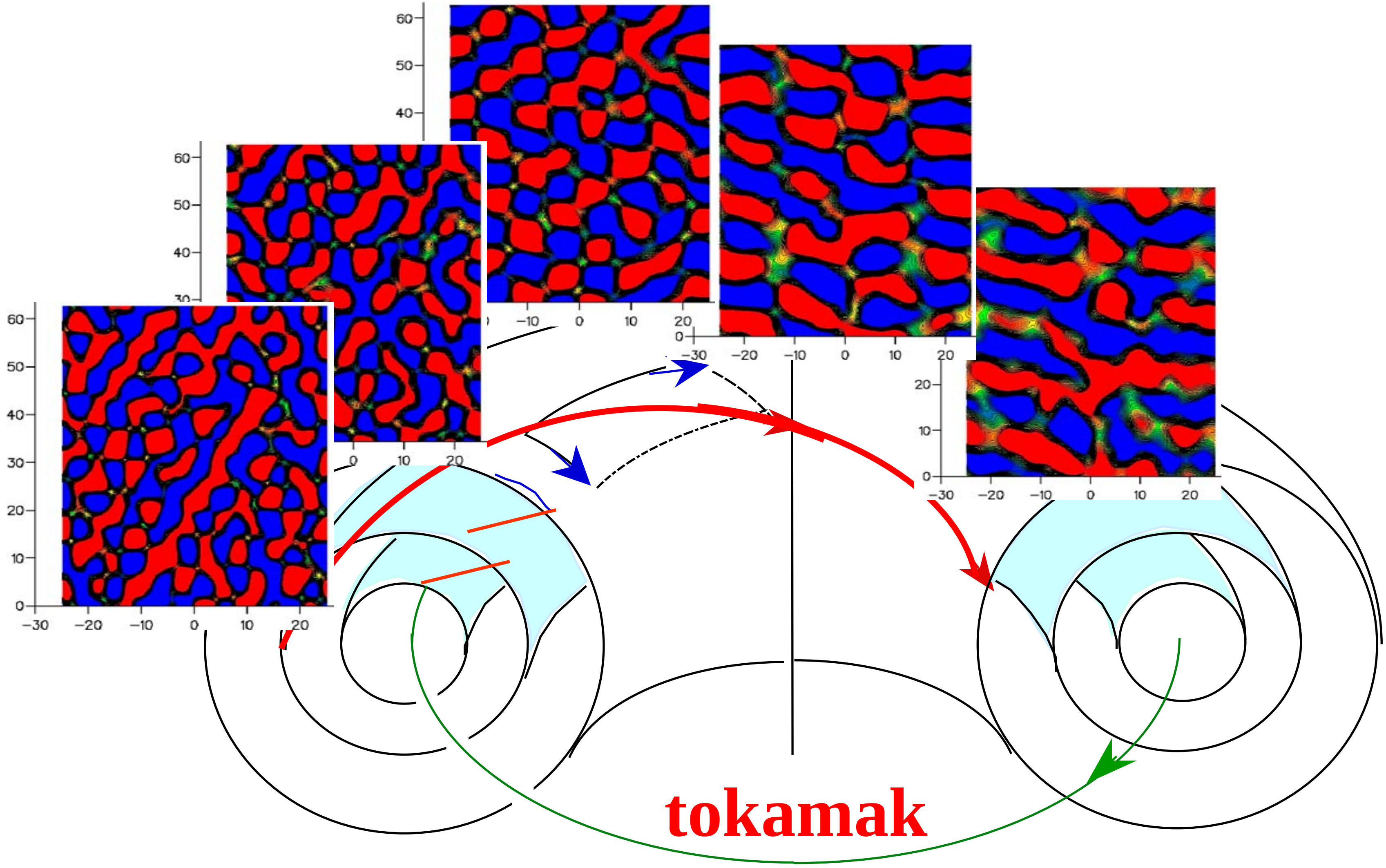




Streamer is characterized by few mode dynamics, electron transport is still low

Streamer structures in toroidal ETG

After ETG saturation, streamers are formed due to the modulation instability

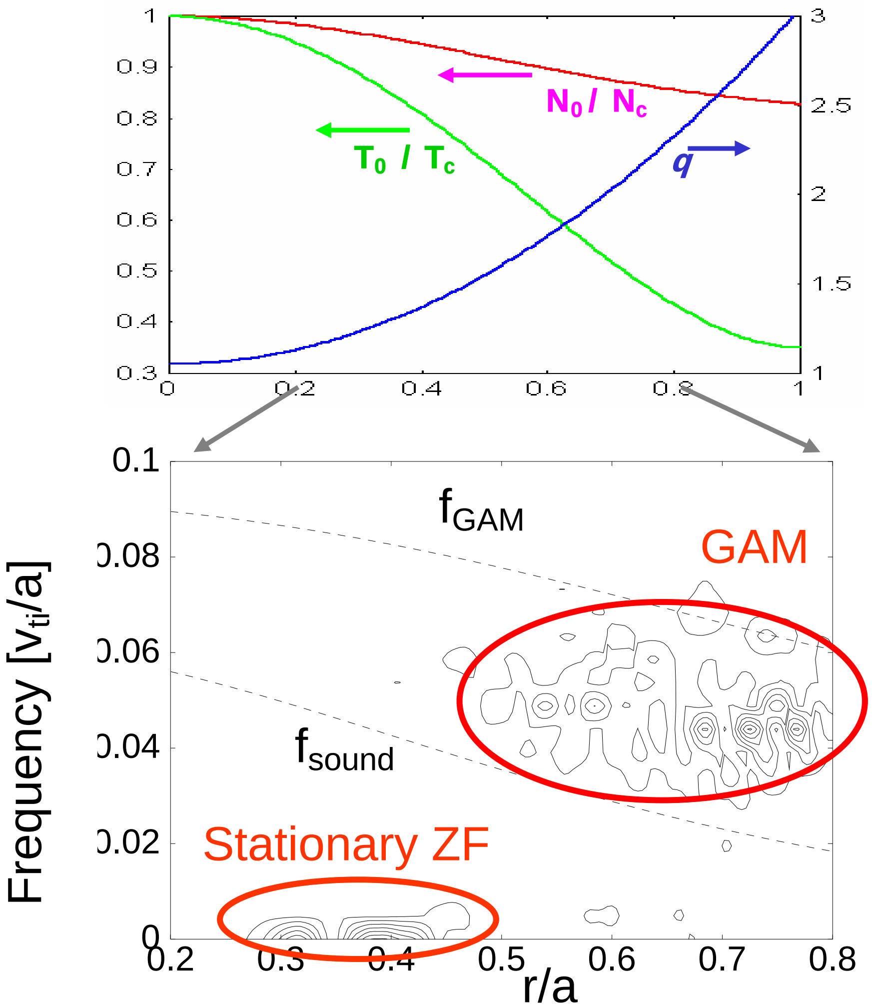


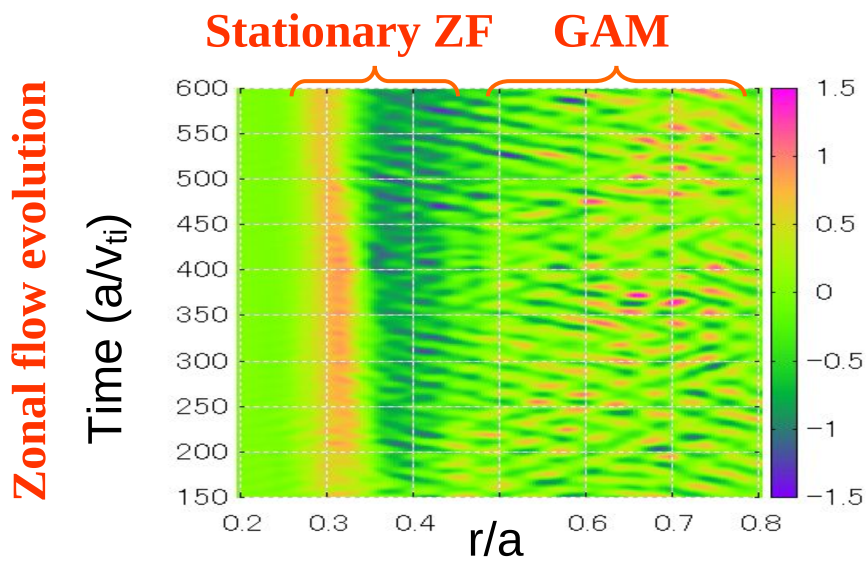
Global behavior of zonal flows in toroidal ITG turbulence and transport controlling

Global ITG simulation in toroidal plasmas

Understand global characteristics of transport and ITB in tokamak;
Explore turbulence interaction and transport controlling

5-field toroidal global Landau-fluid ITG modeling:
Continuity; Vorticity; Parallel ion motion; Parallel electron motion; Ion temperature





low q
Transport
Well suppressed

high q
Suppression
Less effective

Hahm, *et al.*, PoP99

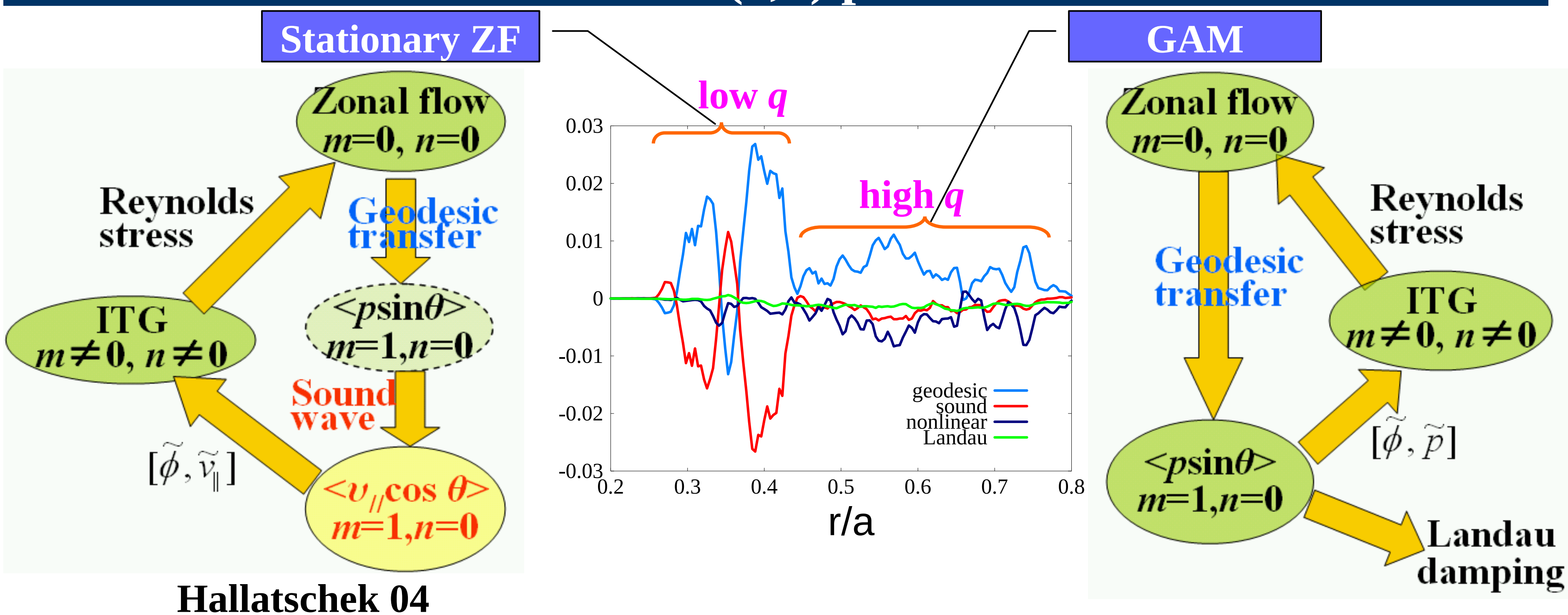
Why different characteristics for zonal flows

Averaged energy balance for pressure perturbation $< p\sin\theta >$

$$\frac{\partial}{\partial t} < p\sin\theta >^2 = \underbrace{- < [\tilde{\phi},\tilde{p}]\sin\theta > < p\sin\theta >}_{\text{Nonlinear transfer}} + \underbrace{(\Gamma+\tau)p_{eq}\frac{a}{qR} < v_\parallel \cos\theta > < p\sin\theta >}_{\text{Sound wave}}$$

$$\underbrace{-(\Gamma-1)\sqrt{\frac{8T_{eq}}{\pi}}\frac{a}{qR} < T_i\sin\theta > < p\sin\theta >}_{\text{Landau damping}} + \underbrace{(\Gamma+\tau)p_{eq}\frac{a}{R} < v_E > < p\sin\theta >}_{\text{Geodesic transfer}}$$

Different role of sound wave in (1,0) pressure fluctuation relaxation



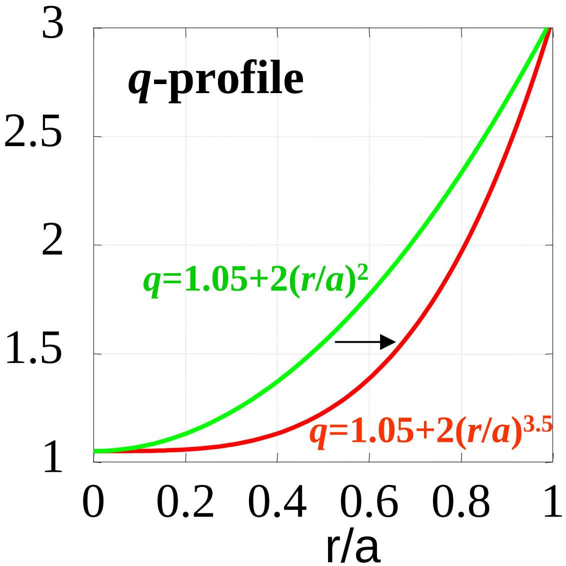
Hallatschek 04
Zonal flow saturation

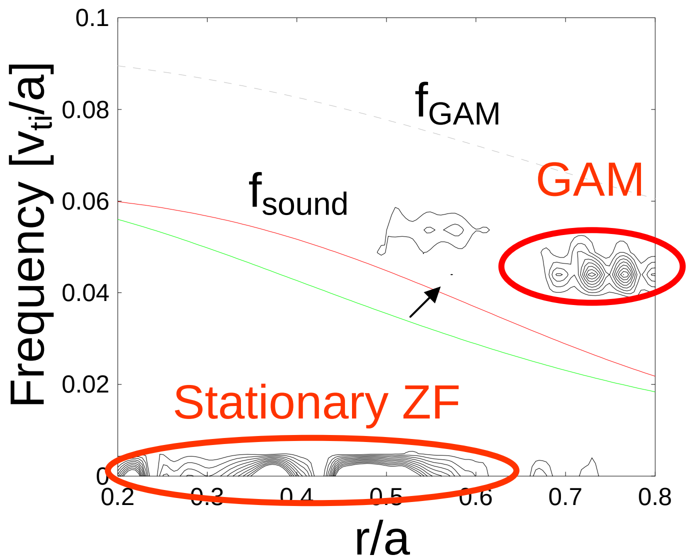
Scott, *et al.* 03

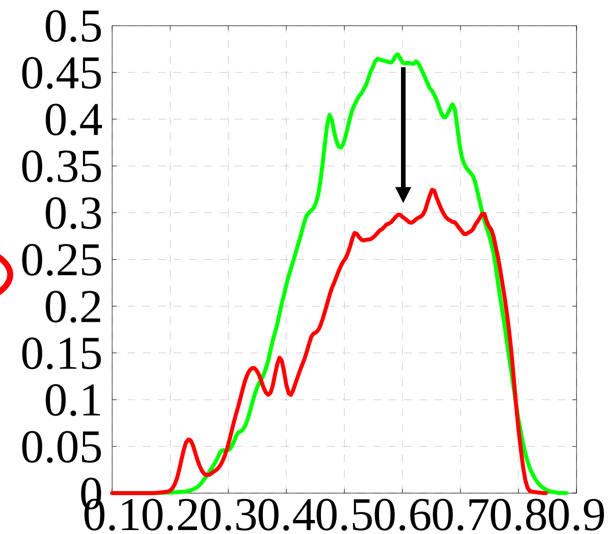
Transport control via zonal flow behavior by *q*-profile

***q*-prfile governs global characteristics of zonal flows in tokamak so that transport may be controllable**

Central *q* profile becomes wider → **Stationary zonal flow region becomes wider** → **Averaged heat flux decreases**







Boundary between stationary and oscillatory (GAM) zonal flow is around $f_{sound} \sim f_{ZF}$

***q* profile is one of the controllable parameters in experiments.**

To understand experimental ITB physics, new theoretical modeling and more simulations are necessary.

Conclusions

Possibility to control transport through dynamics of large-scale structures, zonal flows and streamers, in tokamak is explored.

- ► **Pattern selection of zonal flow or streamer in slab ETG depends on turbulence anisotropy, which may be determined by magnetic shear.**

- ► **Streamers are locally formed around good curvature region in toroidal ETG with higher shear, but averaged electron transport is still low.**

- ► **Stationary and oscillatory (GAM) zonal flows are simultaneously excited in central low *q* and edge high *q* regions, respectively. Transport may be controllable by adjusting profiles, like *q* or shear.**

More results in posters

TH/8-5Ra: **saturation mechanism of enhanced zonal flows; β scaling of electron transport in weak shear ETG; intermittency in toroidal ETG turbulence;…..**

TH/8-5Rb: **details of global simulations; energy flow channels between zonal flow and turbulence; ……..**

Thank you for your attention !