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Local gyro-Landau fluid simulations of toroidal drift wave modes and drift-resistive-inertial ballooning modes in tokamak plasmas

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ABSTRACT

- A local gyro-Landau fluid model is developed for the description of drift-resistive-inertial ballooning modes (DRIBMs) and toroidal drift wave modes in the collisional tokamak plasmas based on the two-fluid reduced Braginskii equations in a generalized ŝ-α geometry.
- Simulation results have demonstrated that while the core transport is dominated by ITG and ETG in the low beta situations or KBM and ETG in the high beta scenarios, the mixture of DRIBM, ITG and ETG could be the principle mechanism responsible for the transport process in the collisional plasma edge.

BACKGROUND

- Recent simulations have attracted a great interest in understanding the type of turbulence in Ohmic and L-mode edge plasmas. Although the standard ITG-TEM models have been successfully in characterizing the transport in the core, it fails to reproduce the high fluctuation level measured at the edge, which increases with the collision rate from the edge toward the last closed flux surface (LCFS).
- One possible candidate that can describe the transport level at the edge of L-modes is the resistive ballooning modes (RBMs). Experiments have shown the electron heat diffusivity measured in the high beta discharges is in agreement with resistive ballooning mode predictions. Recent gyrokinetic simulations using DIII-D, Tore Supra and ITER like wall in JET (JET-ILW) L mode edge parameters have shown that the DRIBMs are linearly unstable and might be related to the onset of H mode.

Gyrofluid model

Model equations

The derivation of the GLF model for DRIBMs takes into account the electron and ion temperature and density perturbations, parallel and perpendicular electron and ion dynamics, collisions, electron inertia, ion gyro-viscous stress and polarization, and diamagnetic and finite beta effects.

$$\partial_t\hat{n}_e = i[\omega_{De}(\Gamma_{1e}+\Gamma_{2e}/2)-\omega_{ne}(\Gamma_{1e}+\eta_e\Gamma_{2e})]\hat{\varphi}-i\omega_{De}(\hat{n}_e+\hat{T}_{e\parallel}/2+\hat{T}_{e\perp}/2)-ik_\parallel c_s\hat{u}_{e\parallel}$$

$$\partial_t\hat{n}_i = i[\omega_{De}(\Gamma_{1i}+\Gamma_{2i}/2)-\omega_{ne}(\Gamma_{1i}+\eta_i\Gamma_{2i})]\hat{\varphi}+i\tau\omega_{De}(\hat{n}_i+\hat{T}_{i\parallel}/2+\hat{T}_{i\perp}/2)-ik_\parallel c_s\hat{u}_{i\parallel}$$

$$\partial_t\hat{A}_\parallel-\mu_e\partial_t\hat{u}_{e\parallel} = -i(1+\eta_e)\omega_{ne}\hat{A}_\parallel-ik_\parallel c_s\Gamma_{1e}\hat{\varphi}+ik_\parallel c_s(\hat{n}_e+\hat{T}_{e\parallel})+i\mu_e\omega_{De}(2\hat{u}_{e\parallel}+\hat{q}_{e\parallel}+\hat{q}_{e\perp}/2)-R_{ei}$$

$$\partial_t\hat{A}_\parallel+\partial_t\hat{u}_{i\parallel} = i\tau(1+\eta_i)\omega_{ne}\hat{A}_\parallel-ik_\parallel c_s\Gamma_{1i}\hat{\varphi}-i\tau k_\parallel c_s(\hat{n}_i+\hat{T}_{i\parallel})+i\tau\omega_{De}(2\hat{u}_{i\parallel}+\hat{q}_{i\parallel}+\hat{q}_{i\perp}/2)-R_{ei}$$

$$\frac{1}{2}\partial_t\hat{T}_{e\parallel} = i\frac{1}{2}(\omega_{De}-\eta_e\omega_{ne})\Gamma_{1e}\hat{\varphi}-ik_\parallel c_s(\hat{u}_{e\parallel}+\hat{q}_{e\parallel})-i\frac{1}{2}\omega_{De}(\hat{n}_e+3\hat{T}_{e\parallel})-S_\Delta^e$$

$$\frac{1}{2}\partial_t\hat{T}_{i\parallel} = i\frac{1}{2}(\omega_{De}-\eta_i\omega_{ne})\Gamma_{1i}\hat{\varphi}-ik_\parallel c_s(\hat{u}_{i\parallel}+\hat{q}_{i\parallel})+i\frac{\tau\omega_{De}}{2}(\hat{n}_i+3\hat{T}_{i\parallel})-S_\Delta^i$$

$$\partial_t\hat{T}_{e\perp} = i\left[\frac{\omega_{De}}{2}(\Gamma_{1e}+4\Gamma_{2e})-\left(\Gamma_{2e}+\eta_e(\Gamma_{1e}+2\Gamma_{2e})\right)\omega_{ne}\right]\hat{\varphi}-ik_\parallel c_s\hat{q}_{e\perp}-i\frac{\omega_{De}}{2}(\hat{n}_e+4\hat{T}_{e\perp})+S_\Delta^e$$

$$\partial_t\hat{T}_{i\perp} = i\left[\frac{\omega_{De}}{2}(\Gamma_{1i}+4\Gamma_{2i})-\left(\Gamma_{2i}+\eta_i(\Gamma_{1i}+2\Gamma_{2i})\right)\omega_{ne}\right]\hat{\varphi}-ik_\parallel c_s\hat{q}_{i\perp}+i\frac{\tau\omega_{De}}{2}(\hat{n}_i+4\hat{T}_{i\perp})+S_\Delta^i$$

$$-\mu_e\partial_t\hat{q}_{e\parallel} = \mu_e f_L\hat{q}_{e\parallel}-i\frac{3}{2}\eta_e\omega_{ne}\hat{A}_\parallel+i\frac{3}{2}k_\parallel c_s\hat{T}_{e\parallel}+i\frac{\mu_e}{2}\omega_{De}(3\hat{u}_{e\parallel}+8\hat{q}_{e\parallel})-K_\parallel^e-K_\Delta^e$$

$$\partial_t\hat{q}_{i\parallel} = -f_L\hat{q}_{i\parallel}+i\frac{3}{2}\tau\eta_i\omega_{ne}\hat{A}_\parallel-i\frac{3}{2}k_\parallel c_s\hat{T}_{i\parallel}+i\frac{\tau\omega_{De}}{2}(3\hat{u}_{i\parallel}+8\hat{q}_{i\parallel})-K_\parallel^i-K_\Delta^i$$

$$-\mu_e\partial_t\hat{q}_{e\perp} = \mu_e f_L\hat{q}_{e\perp}-i\eta_e\omega_{ne}\hat{A}_\parallel-ik_\parallel c_s\Gamma_{2e}\hat{\varphi}+ik_\parallel c_s\hat{T}_{e\perp}+i\frac{\mu_e}{2}\omega_{De}(\hat{u}_{e\parallel}+6\hat{q}_{e\perp})-K_\perp^e+K_\Delta^e$$

$$\partial_t\hat{q}_{i\perp} = -f_L\hat{q}_{i\perp}+i\tau\eta_i\omega_{ne}\hat{A}_\parallel-ik_\parallel c_s\Gamma_{2i}\hat{\varphi}-i\tau k_\parallel c_s\hat{T}_{i\perp}+i\frac{\tau}{2}\omega_{De}(\hat{u}_{i\parallel}+6\hat{q}_{i\perp})-K_\perp^i+K_\Delta^i$$

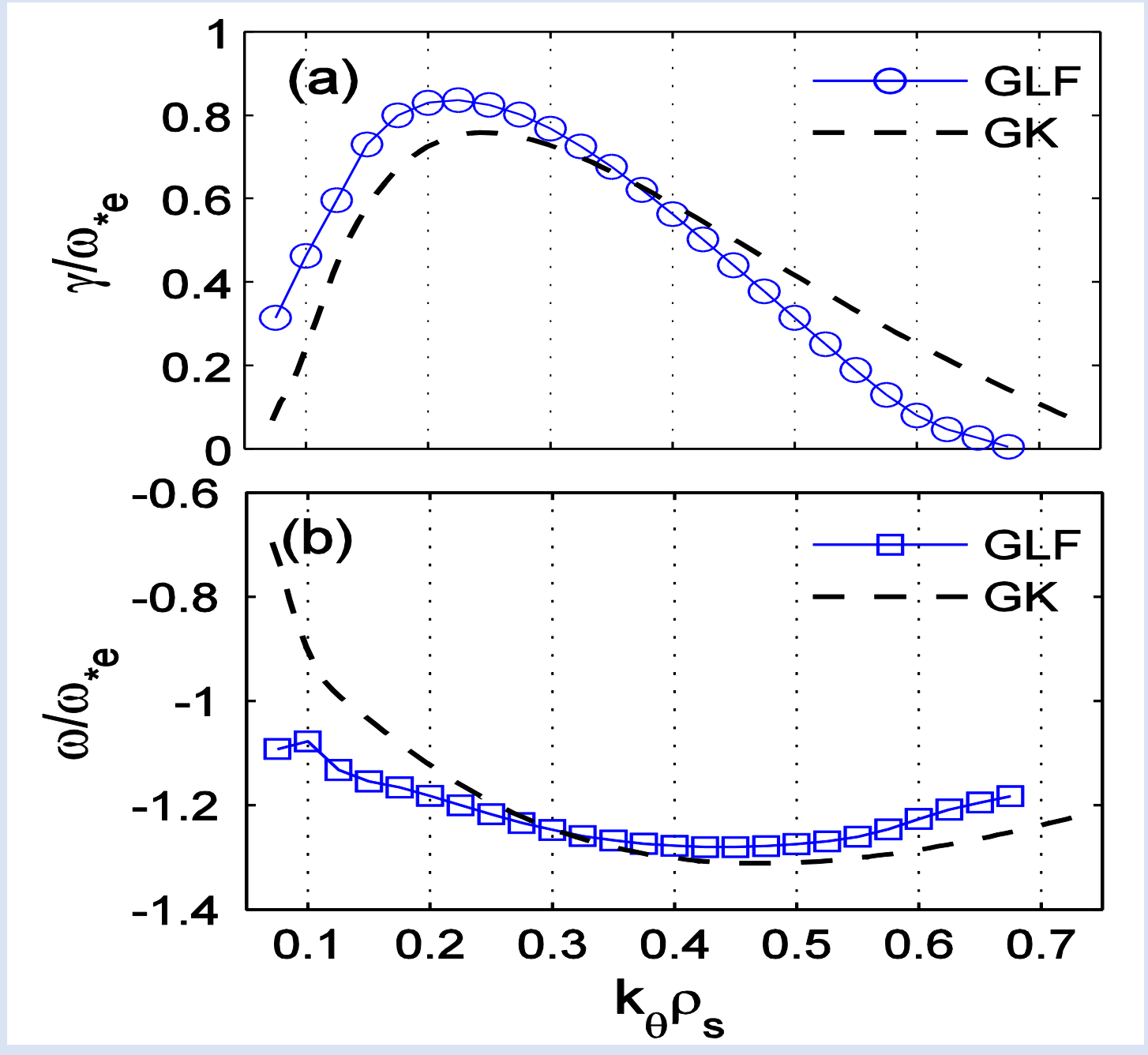

Fig. 1 Comparison of growth rate spectrum between GLF and gyrokinetic simulation for the CBC.

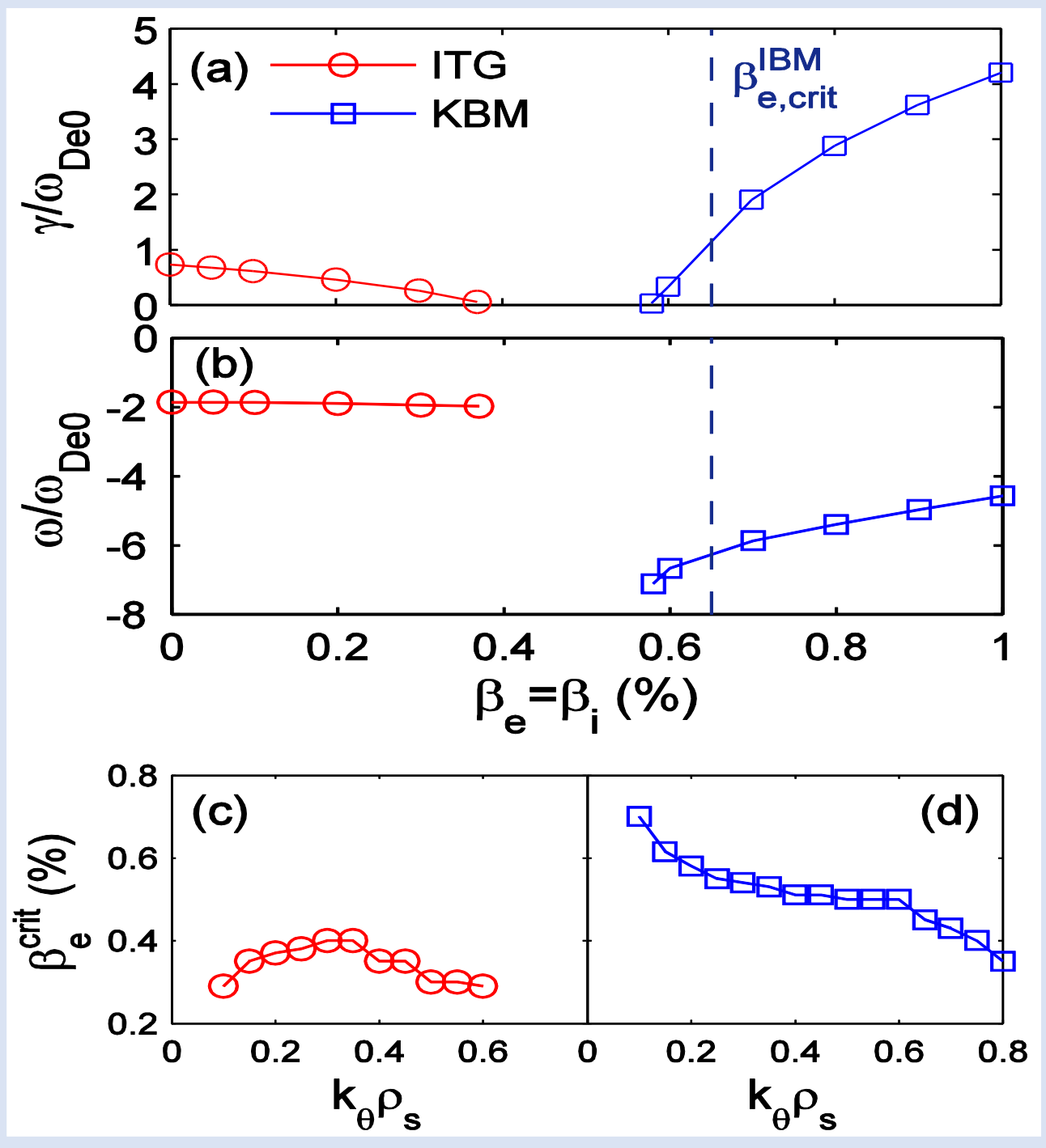

Fig. 2 Dependence of (a) growth rate and (b) real frequency on β_e.

Linear stabilities of DRIBMs and drift wave modes in the collisional plasma edge

There is a general consensus that transport processes dominate energy, particle and momentum transport in fusion plasmas, especially in the plasma edge region. Simulations have shown that these processes are mainly governed by the mixture of drift wave turbulence and resistive ballooning turbulence and the latter may play the dominating role in the edge plasma of Ohmic and L mode discharges where the collisions are relative large due to the low electron temperature.

Table 1. Edge parameters for a JET-ILW discharge.

ρ	n_{e0}	T_{e0}	g_n	$g_{Ti,e}$	q	ŝ	R	B	τ	β_e(%)
0.97	2.6	100	9	55	3.8	4.3	3.0	1.8	1.0	0.0162

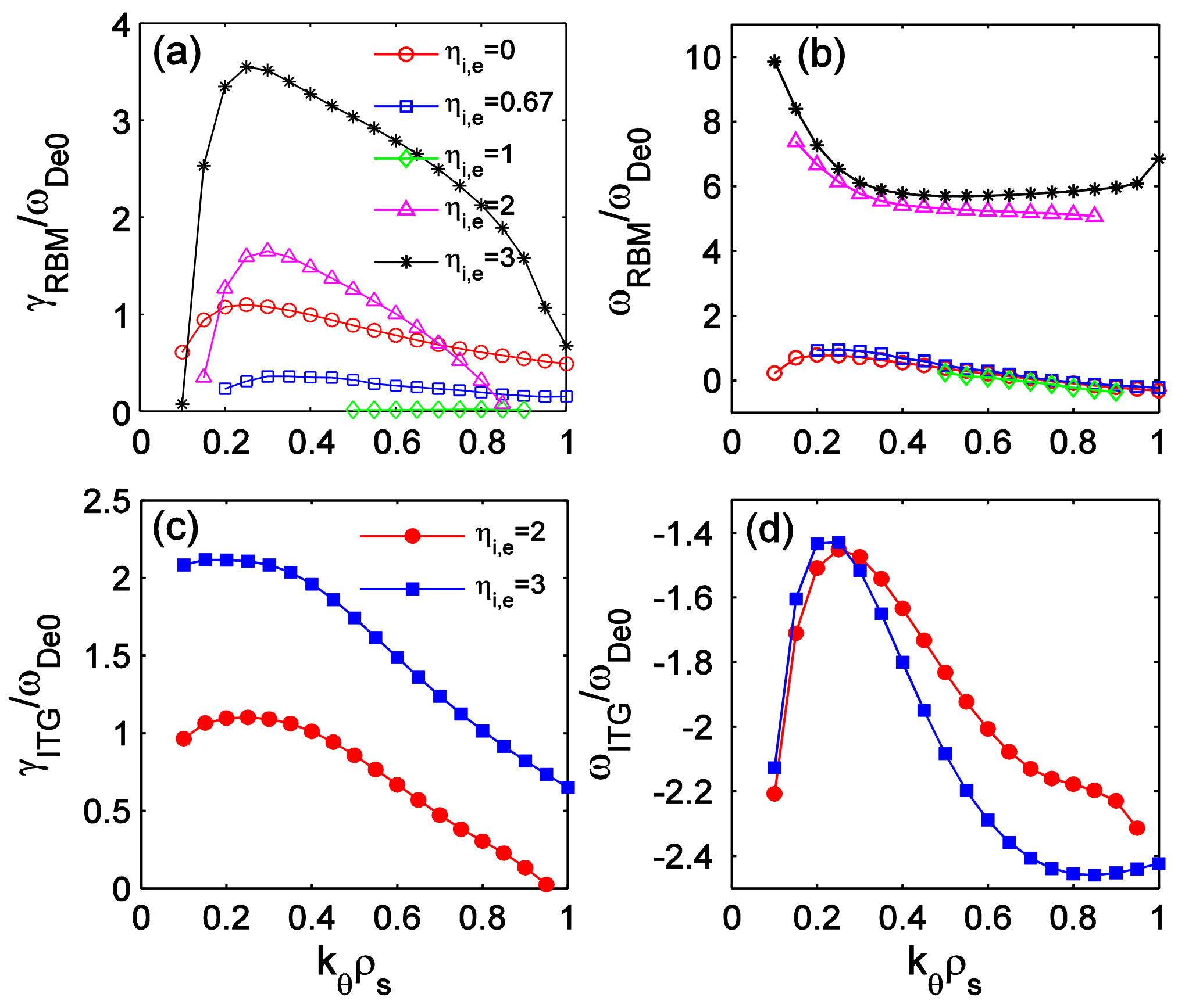

Fig. 3 Eigenvalue spectrum of the growth rate and real frequency. (a) and (b) are for DRIBM while (c) and (d) are for ITG.

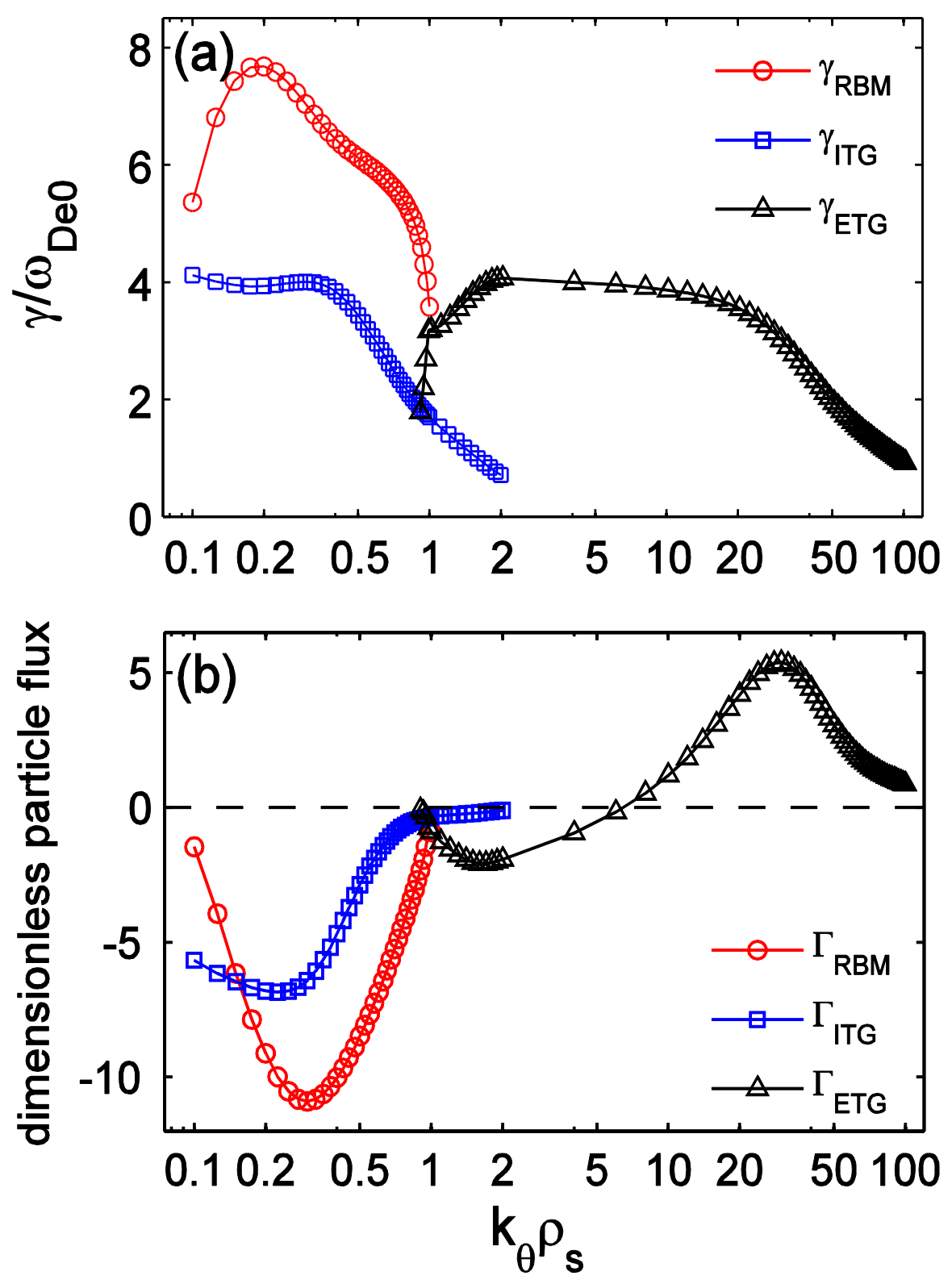

Fig. 4 (a) growth rate and (b) dimensionless particle flux as a function of $k_\theta\rho_s$ for JET-ILW edge parameters.

CONCLUSION

- The electromagnetic gyro-Landau fluid model in the collisional plasma has been developed, which incorporates the DRIBM, ITG, KBM and ETG. It has shown that the dominating instabilities are the mescal-scale ITGs and short-scale ETGs in the low βe discharges, while for large βe, the transport is controlled by long wavelength KBMs and shot-scale ETGs.
- Transport process in the edge is mixed by intermediate-scale DRIBM and ITG and short-scale ETG turbulence. The ITG and DRIBM produce the inward particle transport under L mode edge plasma conditions with the contribution of the latter much larger than the former. The combination of these effects has strongly suggested that turbulent transport is predominated by DRIBMs in the collisional plasma edge.

ACKNOWLEDGEMENTS / REFERENCES

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