MUTLISCALE GYROKINETIC SIMULATIONS OF THE INTERACTION BETWEEN TURBULENCE AND FISHBONE

Yuehao Ma[1], Huishan Cai[1,*], Pengfei Liu[2], Z. Lin[3], Bin Zhang[4], and Jian Bao[2]

[1]University of Science and Technology of China, Hefei 230026, China
[2]Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China
[3]Department of Physics and Astronomy, University of California, Irvine, California 92697, United States of America
[4]Institute of Plasma Physics, Chinese Academy of Sciences, Hefei 230031, China

Email: hscai@mail.ustc.edu.cn

Internal Transport Barriers (ITBs) are regions in tokamak plasmas where reduced core transport leads to steep pressure gradients, indicating improved confinement. Moreover, the associated steep pressure gradients generate a high bootstrap current fraction, aiding plasma current drive and enabling potential steady-state operation. These advantages make ITBs important for advancing fusion energy research, motivating extensive studies on advanced scenarios incorporating ITBs.

Experiments have shown that fishbone instabilities frequently occur alongside ITBs in tokamak plasmas in ASDEX-U, EAST, HL-2A [1-4] and so on. It suggests a strong correlation between the two phenomena. In EAST [2], the fishbone and ITB formation nearly occur simultaneously, and their sequence is hard to be distinguished by diagnose. Whether fishbone causes the ITB formation or not is still unclear.

In this work, based on the EAST discharge where ITBs form in presence of the weakly negative magnetic shear [4,5], for the first time, we conducted the cross-scale coupling simulations between microturbulence and fishbone instability self-consistently using the gyrokinetic toroidal code (GTC). It is found that fishbone-induced zonal flow not only effectively reduces the ITG turbulence saturation amplitude, but also reduces the ion thermal conductivity to the neoclassical transport level. It can be proposed that fishbone potentially facilitates the formation or maintenance of ITBs, which is benefit for the plasma confinement in the hybrid scenario of ITER.

As shown in Fig.1a, the cross-scale self-consistently electromagnetic simulation between multi-n electromagnetic ITG and fishbone has been carried out. It can be found that the ITG turbulence saturation amplitude is effectively reduced from the order of 10^{-2} to 10^{-4}. Correspondingly, the ion heat transport coefficient is reduced to the neoclassical transport level, as shown in Fig.1c. To clarify the physics, using the zonal flow generated by the fishbone mode as the equilibrium flow, only the electromagnetic simulation on ITG is carried out, as shown in Fig.1b. It agrees well with that obtained from the power balance analysis by the ONETWO code. It can be seen that the saturation amplitude of ITG turbulence also decreases to the level of 10^{-4}. It indicates that fishbone induced zonal flow or radial electric field effectively suppress ITG turbulence, potentially facilitating the formation of ITBs.

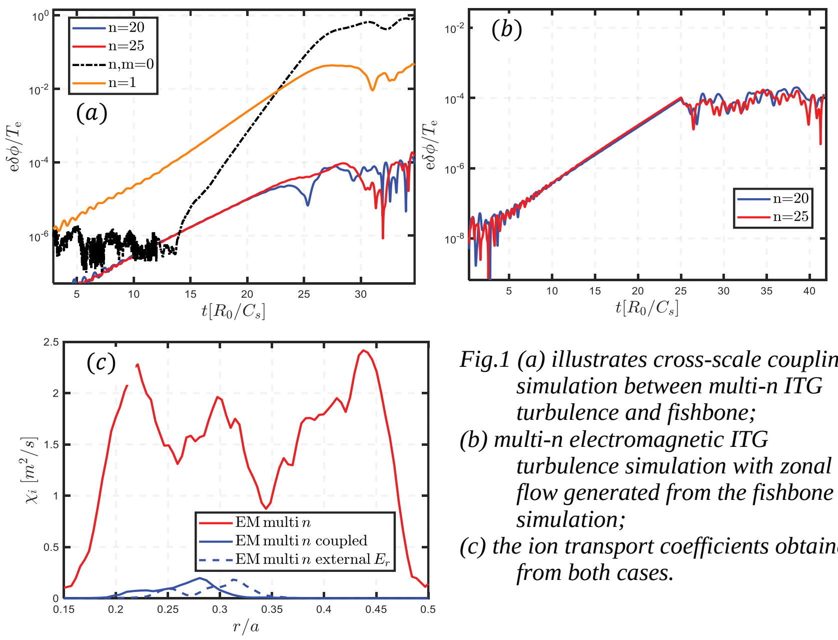


Fig.1 (a) illustrates cross-scale coupling simulation between multi-n ITG turbulence and fishbone;
(b) multi-n electromagnetic ITG turbulence simulation with zonal flow generated from the fishbone simulation;
(c) the ion transport coefficients obtained from both cases.

On the other hand, the redistribution of energetic ions by fishbone is weakly affected by ITG turbulence, as shown in Fig.2. It can be seen that the perturbed density of energetic ions with ITG keeps almost unchanged.

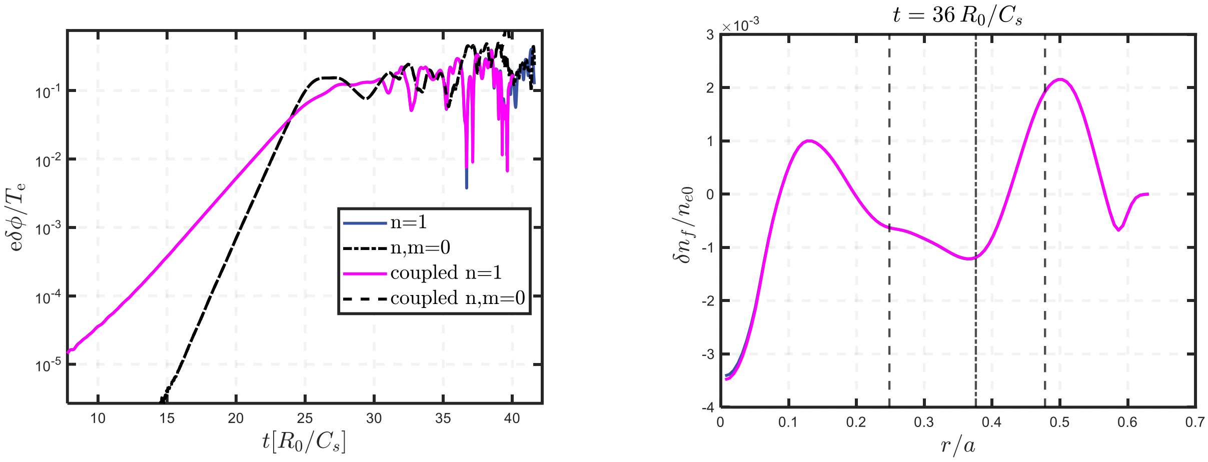
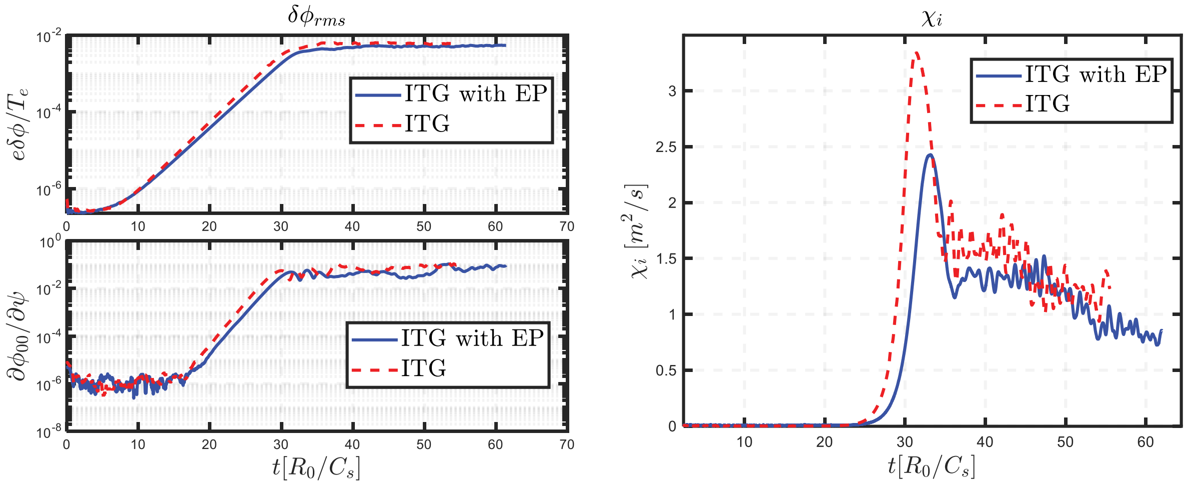


Fig.2 (a) The fishbone amplitudes without ITG (blue line) and with ITG (pink line) ;
(b) The perturbed of energetic ion density by fishbone without ITG (blue line) and with ITG (pink line)

In addition, the effect of energetic ions on ITG is weak, as shown in Fig.3. It can be seen that both the saturation amplitudes of ITG and the ion thermal conductivities with and without energetic ions are almost the same.



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