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Long-time perturbative computation and self-organized evolution of Internal Transport Barrier in fusion plasmas

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Internal transport barriers (ITB) have been observed in many tokamaks [1, 2], and the ITB in hybrid scenario, which has a weak positive magnetic shear near the magnetic axis, is crucially important for the International Thermonuclear Experimental Reactor [3]. To understand the ITB formation dynamics, we need a long-time nonlinear gyrokinetic (GK) turbulence simulation.

The perturbative computation is widely used in the GK simulation. In the perturbative computation, the full distribution function is partitioned into the perturbative part and the equilibrium part, and it solves the perturbed instead of the full distribution function. Since the perturbed distribution is usually much smaller than the full distribution, it has relatively higher precision. However, in a long-time simulation, especially in the case with an external source, the perturbed distribution may become large enough to be comparable to the equilibrium distribution.

Recently, the Neighboring Equilibrium Update (NEU) method has been proposed to avoid this secularity problem in a perturbative computation [3, 4]. Since the system is defined by the distribution function and fields, the basic idea of the NEU method is that when the perturbation is large enough, one can repartition the full distribution (field), which is the summation of the known perturbed and the equilibrium parts, into the updated perturbed and equilibrium parts. The NEU does not change the system, and in the updated equilibrium, the equilibrium distribution is a constant of motion in the equilibrium field.

With the NEU method, the perturbative nonlinear global GK code, NLT [4], has been used to successfully carry out a long-time simulation of the ITB formation in the ion temperature-gradient (ITG) turbulence in a tokamak plasma with external heating. The simulated evolution of the ion temperature and the radial electric filed is shown in Fig. 1. The simulation results agree well with the experimental observations in various aspects.

It is found that the ITB emerges near the magnetic axis, around which the magnetic shear is weak, due to an inward propagating turbulence avalanche. The ITB is identified as a self-organized critical (SOC) structure, since it is insensitive to the initial condition and robust to perturbations. The outward expansion of the ITB is the catastrophe of SOC structure induced by an outward propagating avalanche. Both the turbulence Reynolds stress [5] and turbulence energy flux [6] are crucially important in nonlinearly generating the zonal structure of the radial electric field. The picture of ITB expansion can be summarized as follows. When the external heating raises the temperature in the ITB layer to a threshold, the ITG mode becomes unstable there and excites an outward propagating avalanche, which expands the well structure of the radial electric field due to the turbulence Reynolds stress [5] and turbulence energy flux [6], and this expands the ITG stabilization region due to the fact that the radial structure of the zonal radial electric field is expanded.

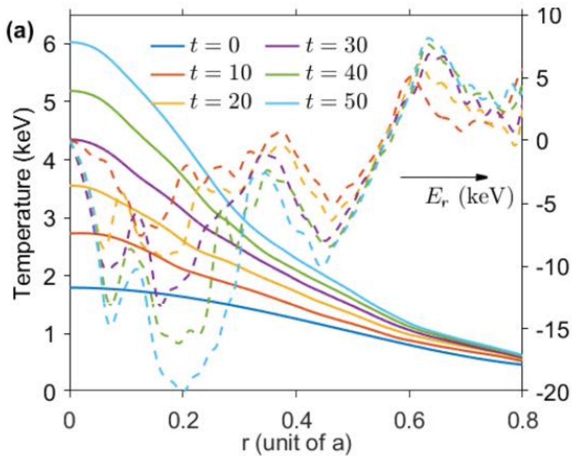

Fig. 1. ITB formation in an ion-temperature-gradient driven turbulence.

References:

[1] J. Strachan, et al., Phys. Rev. Lett. 58, 1004 (1987); Y. Koide, et al., Phys. Rev. Lett. 72, 3662 (1994); C. L. Rettig, et al., Phys. Plasmas 5, 1727 (1998).

[2] E. J. Doyle, et al., Nucl. Fusion 47, S18 (2007).

[3] S. Wang, Phys. Plasmas 19, 062504 (2012); Phys. Plasmas 20, 082312 (2013).

[4] S. Wang, Z. Wang, T. Wu, Phys. Rev. Lett. 132, 065106 (2024).

[5] P. H. Diamond, Y. L. Liang, B. A. Carreras, and P. W. Terry, Phys. Rev. Lett. 72, 2565 (1994).

[6] S. Wang, Phys. Plasmas 24, 102508 (2017).