6th Asia-Pacific Conference on Plasma Physics, 9-14 Oct, 2022, Remote e-conference

The soliton propagation and energy transfer in the coupled drift wave and energetic particle induced geodesic acoustic mode system

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The anomalous transport, generally accepted to be triggered by the micro-turbulence, is a major concern for the tokamak confinement. The micro drift wave (DW) turbulences, can be driven unstable by the plasma pressure gradient intrinsic to magnetically confined plasmas, and are thus, ubiquitous modes in the magnetically confinement devices [1]. To achieve better performance, the DW turbulence should be regulated to lower the transport level. It is not only the amplitude of the DW in its unstable region that matters, but also the radial redistribution of the wave intensity due to the radial propagation of the DW envelope from its linearly unstable to stable region, i.e., turbulence spreading [2]. Previous investigations suggest that the turbulence spreading contributes to the nonlocal transport and core-edge coupling, i.e., the turbulent transport is dependent on the plasma parameters elsewhere [2,3].

On the one hand, zonal flows (ZFs) are suggested to be the mediator for the formation of DW-ZFs solitons, resulting in the turbulence spreading [2, 4]. ZFs are radial electric field with $n = 0$ and $m \approx 0$ electric potential, which consist of the zero-frequency ZF (ZFZF) and the finite frequency geodesic acoustic mode (GAM). The formation of the DW-ZFs solitons was firstly investigated by Ref. [5] using the two-field model, in which the balance of the DW dispersiveness and nonlinear trapping effect due to the ZFZF results in the formation of the DW-ZFZF soliton. The two-field model is able to describe the long time evolution of the DW-ZFs nonlinear system. This approach was then used to investigate the DW-GAM system, and the formation of the DW-GAM solitons is observed [6]. Moreover, due to the finite frequency of GAM, it can be excited by the velocity space anisotropy of the energetic particles (EPs), i.e., the EPs-induced GAM (EGAM). EGAM excitation by externally injected EPs is also proposed as an active control of DW turbulence. Thus, the investigations on the DW-EGAM nonlinear system is a natural and necessary extension of the nonlinear mechanisms for the DW turbulence spreading, especially the nonlinear energy transfer of the nonlinear coupled system, raised due to the unexpected “excitation” of DW turbulence by EGAM [7].

Motivated by the above-mentioned advances, in this work, the nonlinear interaction between the DW and EGAM is systematically investigated using the DW-EGAM two-field model, based on the nonlinear gyrokinetic framework. Four scenarios are considered in this work, which are the combination of with/without linear EPs drive and the initially small/finite amplitude EGAM. The enhanced soliton velocity is found for the DW-EGAM solitons compared to that without the linear EPs drive [4], indicating that the linear EPs drive might enhance the turbulence spreading. The spectrum of the DW and GAM/EGAM are investigated, and it is found that the accelerated propagation might be related to the excitation of micro-scale DW (high-kr harmonics). Two conservation laws of the nonlinear DW-EGAM system are derived and verified numerically, including the energy conservation law, to investigate the energy transfer. The total energy can be decomposed to the energy of the DW, GAM/EGAM, and the interaction, according to where they come from. It is found that the energy of the DW always decreases and that of the EGAM/GAM always increases for four scenarios, so the energy transfer from the EGAM/GAM to the DW does not happen in this system. Thus, this work offers new insight to the nonlinear DW suppression mechanism through the energy transfer to the EGAM. Finally, the DW is damped by the EGAM linearly and nonlinearly, leading to the improvement of the confinement. However, the enhancement of the DW turbulence spreading might offset the positive effect of the EGAM on the plasma confinement. The overall result needs further investigation.

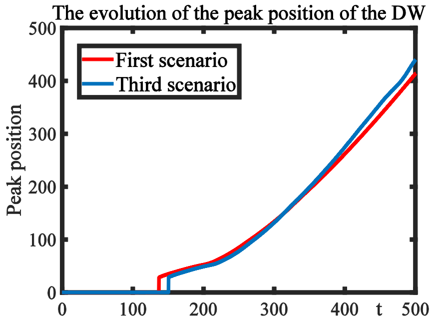

Fig.1 Evolution of the DW peak position

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