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Soliton generation and drift wave turbulence spreading by geodesic acoustic mode excitation

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Anomalous particle and energy transport in magnetically confined fusion devices, generally accepted to be triggered by pressure gradient-driven drift wave (DW) turbulence, is one of the major channels for thermal plasma transport, and, degradation of plasma confinement [1]. The spontaneous excitation of zonal flows (ZFs), consists of zero frequency ZF (ZFZF) and its finite frequency counterpart geodesic acoustic mode (GAM), is a significant component of the DW nonlinear dynamics and the self-regulation of the DW, which has been investigated intensively in past few decades [2,3].

The spontaneous excitation of ZFs by the DW is referred to as the "linear" growth stage of the nonlinear process, which can be investigated by the model of modulation/parametric decay instability (PDI), where the DW is separated into pump DW and sidebands. However, the models mentioned above can not be applied to analyze the nonlinear saturated stage, even if the feedback of the daughter waves to the mother wave is considered [4]. A two-field model for the DW-ZFZF system, without separating the DW into pump wave and sidebands, was thus constructed to investigate the long time scale nonlinear evolution of DW-ZFZF system in the slab geometry [5].

Motivated by these works, the coupled two-field DW-GAM equations are derived in the nonlinear gyrokinetic framework with the DW treated as a whole, which governs the fully nonlinear dynamics of DW and GAM system. There are two phases with distinctive features present in the nonlinear process. In the "early" stage of nonlinear evolution, the fully nonlinear two-field model recovers the intensively studied PDI model by separating the DW into pump wave with fixed amplitude and lower sideband with much smaller amplitude. Besides, numerical solution of the two-field equations recovers the main results of Ref. [6], i.e., GAM growth rate is proportional to pump DW amplitude, short wavelength kinetic GAM excitation is favored and enhanced radial propagation of the nonlinearly generated GAM.

In the nonlinear saturated phase, the soliton structures are observed to form as a result of the self-trapping by the nonlinearly generated GAM, as the localization by GAM balancing DW kinetic dispersiveness. Moreover, the k_r spectrum of DW evolves to higher k_r regime, indicating higher velocity for the nonlinearly generated solitons. Above all, the DW-GAM soliton structures can propagate into a much broader radial region with $\Delta r \sim t$, rather than the linear dispersive process with $\Delta r \sim \sqrt{t}$, and thus, can enhance turbulence spreading from linearly unstable to stable region, potentially responsible for nonlocal transport and core-edge interaction. The DW-GAM two-field model presented in this work, provides necessary tools into understanding the fully nonlinear dynamics of the DW and GAM.

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