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Nonlinear saturation of toroidal Alfvén eigenmode via ion induced scattering in nonuniform plasmas

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In magnetically confined fusion plasmas, shear Alfvén waves (SAWs) can be resonantly excited by energetic particles (EPs), and in turn, induce EP anomalous transport loss across magnetic surfaces, resulting in plasma performance degradation and possibly damage of plasma facing components. With the EP anomalous transport rate determined by the amplitude and spectrum of the SAW instabilities, it is necessary to investigate the nonlinear evolution and saturation process of SAW instabilities. Taking the toroidal Alfvén eigenmode (TAE) as a representative paradigm, refs. [1,2] investigated the nonlinear saturation of TAE via ion induced scattering and obtained the saturation amplitude for TAE and the corresponding EP transport coefficient. While the above works on parametric decay process generally assumed uniform plasmas, recent research [3] found that plasma nonuniformity can quantitatively enhance the parametric decay process of kinetic Alfvén waves (KAWs), and qualitatively, the parity breaking of the KAW spectrum results in considerable convective plasma transport and possible confinement improvement.

Motivated by ref. [3], we investigated the parametric decay process of TAE in nonuniform plasmas due to its correspondence with KAW. In this work [4], the process of a pump TAE decaying into a sideband TAE and drift sound wave (DSW) quasi-mode is considered. It is found that, the nonlinear scattering cross-section of this parametric decay process is significantly enhanced as expected, and the spontaneous decay condition is modified qualitatively. To be more specific, in uniform plasmas, pump TAE spontaneously decays into sideband TAE with lower frequency, while in nonuniform plasmas, it decays into sideband TAE with higher toroidal mode number n. Considering burning plasmas in ITER-like tokamaks where a rich spectrum of TAEs exist, the nonlinear evolution behavior of TAE spectrum could be significantly influenced due to this ion induced scattering process. Thus, based on this three-wave parametric decay model, we further extended it into multiple-mode case and investigated the nonlinear evolution process of TAE spectrum in nonuniform plasmas [5]. Specially, the wave-kinetic equation describing the nonlinear evolution of TAE spectrum is derived. By analytically and numerically solving this equation, the nonlinear evolution and saturation of TAE spectral intensity is analyzed, the overall magnetic perturbation amplitude induced by TAE spectrum is estimated, and the potential impact on momentum transport and plasma confinement is discussed.

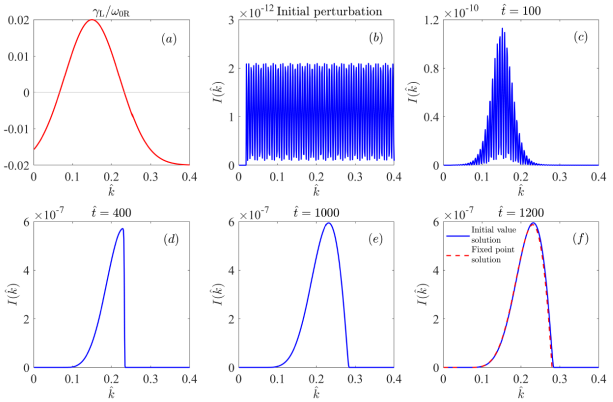

Figure 1. Plots of TAE spectrum evolution and saturation process by initial value solution and comparison with fixed point solution. Here, $\hat{t} = \omega_{0R} t$, figures (a) and (b) are the provided linear growth rate distribution and random initial perturbation respectively. The evolution and saturation process of TAE spectrum is shown in figures (c), (d) and (e). A comparison of the final saturation spectrum with fixed point solution is given in figure (f).

References

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Note: Abstract should be in (full) double-columned one page