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Nonlinear reversed shear Alfvén eigenmode saturation due to spontaneous zonal current generation

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Energetic particles (EPs), especially alpha particles, can excite the shear Alfvén wave (SAW) instability in tokamak plasmas. Correspondingly, the shear Alfvén wave instability in turn affects the behavior of EPs, resulting in EPs transport loss. SAW instabilities include energetic particle modes (EPM) excited on the continuum; and multiple Alfvén eigenmodes (AEs) excited in the forbidden gap of the continuum, such as toroidal Alfvén eigenmode (TAE) , reverse shear Alfvén eigenmode (RSAE) and so on. The frequency and radial localization of RSAE are directly determined by safety factor q. RSAE localizes at the minimum of q, and it is very sensitive to the change of q with its frequency may sweeping between the TAE and BAE. In future magnetic confinement fusion devices such as ITER, typically characterized by reversed shear configuration, the minimum of q localizes at the core region of the device where EPs generate, so the RSAE may be excited first [1]. Therefore, studying the excitation, evolution and saturation of RSAE is important to the future study of magnetic confined controllable nuclear fusion.

The nonlinear zero frequency zonal structure (ZFZS) excitation by RSAE is an important channel of the RSAE saturation. The zonal structure (ZS), including the zonal flow (ZF) and the zonal current (ZC), are known to play important self-regulatory roles on microscale drift wave type instabilities by scattering drift waves into short radial wavelength stable domains [2,3].

Based on the work of the TAE [4] and BAE [5] nonlinearly exciting the ZFZS, we use the nonlinear gyrokinetic theory to study the nonlinear RSAE self-modulation due to ZFZS excitation. Different from TAE confined in the middle of two rational surfaces and BAE confined on the rational surface, the frequency and radial location of the RSAE is determined by q_{min}, and we obtain a more general dispersion relation describing the modulational instability dispersion relation of ZFZS excitation by AEs. At the same time, we propose a unique channel of RSAE saturation, which is similar with the mechanisms proposed in [6,7] of TAE saturation. Due to the generation of ZC, the SAW continuum and q-profile may be directly modulated, which further modifies the coupling between RSAE and SAW continuum, resulting to RSAE nonlinear saturation.

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